US007788981B2

(12) **United States Patent**
Schmid et al.

(10) **Patent No.: US 7,788,981 B2**
(45) **Date of Patent: Sep. 7, 2010**

(54) **PRESSURE MEASUREMENT DEVICE AND SYSTEM, AND METHOD FOR MANUFACTURING AND USING THE SAME**

(75) Inventors: **Noa Schmid**, Kriens (CH); **Helmut Knapp**, Ebikon (CH); **Janko Auerswald**, Lucerne (CH); **Christian Andreas Bosshard**, Lausen (CH); **Mark Fretz**, Lucerne (CH); **Anne-Claire Pliska**, Hausen am Albis (CH)

(73) Assignee: **CSEM Centre Suisse d'Electronique et de Microtechnique SA - Recherche et Developpement**, Neuchatel (CH)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 170 days.

(21) Appl. No.: **12/075,864**

(22) Filed: **Mar. 14, 2008**

(65) **Prior Publication Data**

US 2008/0223141 A1 Sep. 18, 2008

Related U.S. Application Data

(60) Provisional application No. 60/907,013, filed on Mar. 16, 2007.

(51) **Int. Cl.**
G01L 9/06 (2006.01)

(52) **U.S. Cl.** **73/721**; 73/715; 361/283.1

(58) **Field of Classification Search** .... None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,440,198 A 4/1948 Green
2,602,329 A 7/1952 Clark
4,655,088 A 4/1987 Adams
5,257,547 A * 11/1993 Boyer 73/756
5,359,887 A 11/1994 Schwab et al.
5,983,727 A 11/1999 Wellman et al.
6,263,741 B1 * 7/2001 Woias 73/861.47

(Continued)

FOREIGN PATENT DOCUMENTS

EP 0 813 049 12/1997

(Continued)

OTHER PUBLICATIONS

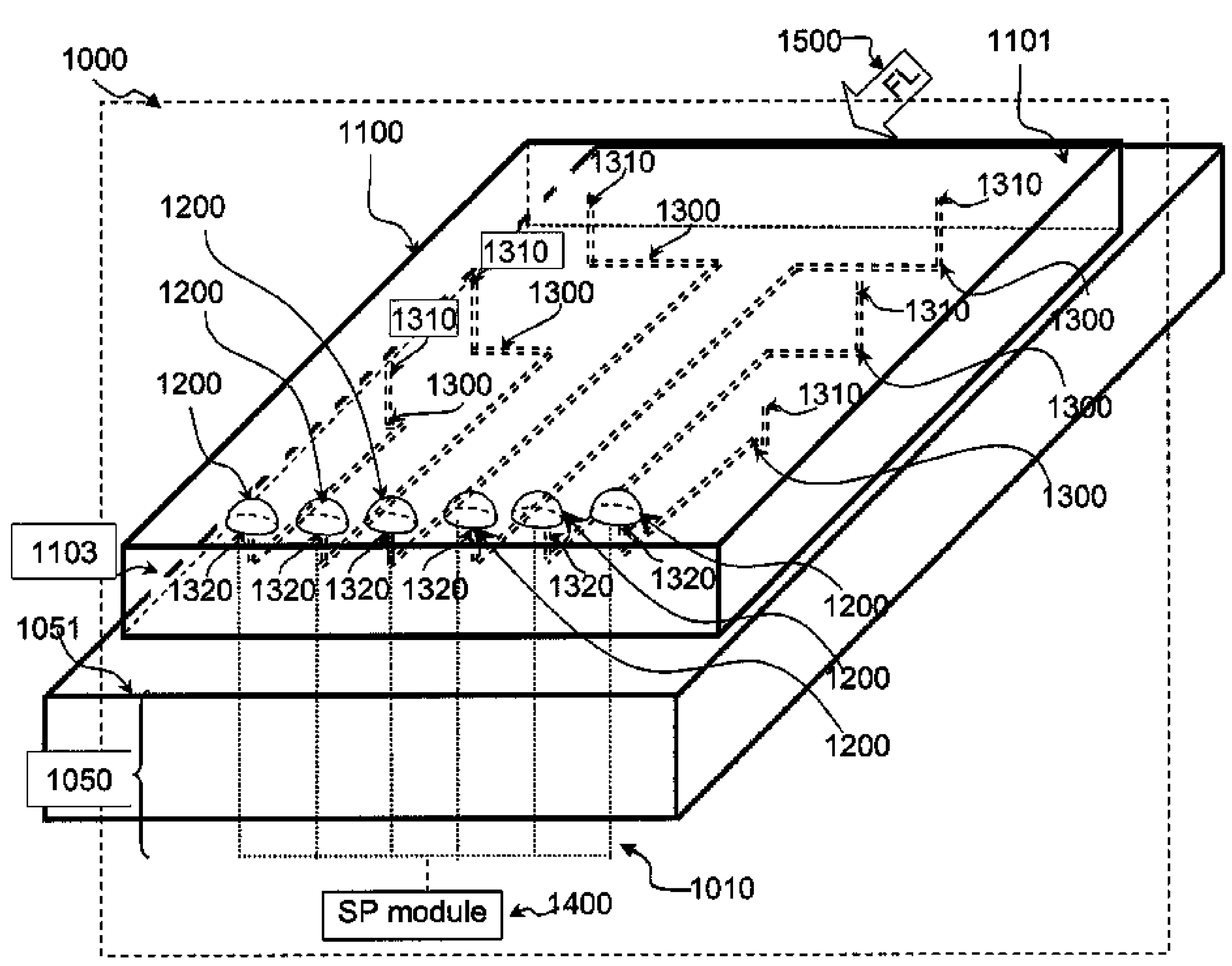
Xiao, G., et al: "A Pressure Sensor Using Flip-Chip on Low-Cost Flexible Substrate," 2001 Electronic Components and Technology Conference, IEEE (5 pp), 2001.

Primary Examiner—Lisa M Caputo
Assistant Examiner—Jermaine Jenkins
(74) *Attorney, Agent, or Firm*—Weingarten, Schurgin, Gagnebin & Lebovici LLP

(57) **ABSTRACT**

The present invention discloses a pressure measurement device comprising: a substrate that includes at least one pressure sensing module and at least one fluid-conductive channel, wherein each channel has a first aperture and a second aperture. The substrate is flexible such that the pressure measurement device is conformably adjustable onto an object's surface. The first aperture is located on the substrate such that when the substrate is suitably adjusted onto the object's surface, the first aperture is open to the exterior of the object's surface. The pressure sensors module is operatively connected to at least one of the second apertures, such that the at least one pressure sensing module is generally being subjected to the pressure being present at the first aperture.

14 Claims, 11 Drawing Sheets



U.S. PATENT DOCUMENTS

6,298,730 B1 * 10/2001 Yamagishi et al. 73/723
6,484,589 B1 * 11/2002 Brock 73/861.18
6,588,281 B2 * 7/2003 Kurtz et al. 73/754
6,595,066 B1 * 7/2003 Kurtz et al. 73/721
6,662,647 B2 12/2003 Schoess et al.
6,826,968 B2 12/2004 Manaresi et al.
7,127,948 B2 10/2006 Tavares et al.
2006/0156805 A1 7/2006 Sawada
2006/0179952 A1 8/2006 Tavares et al.

FOREIGN PATENT DOCUMENTS

EP 1 785 713 5/2007

* cited by examiner

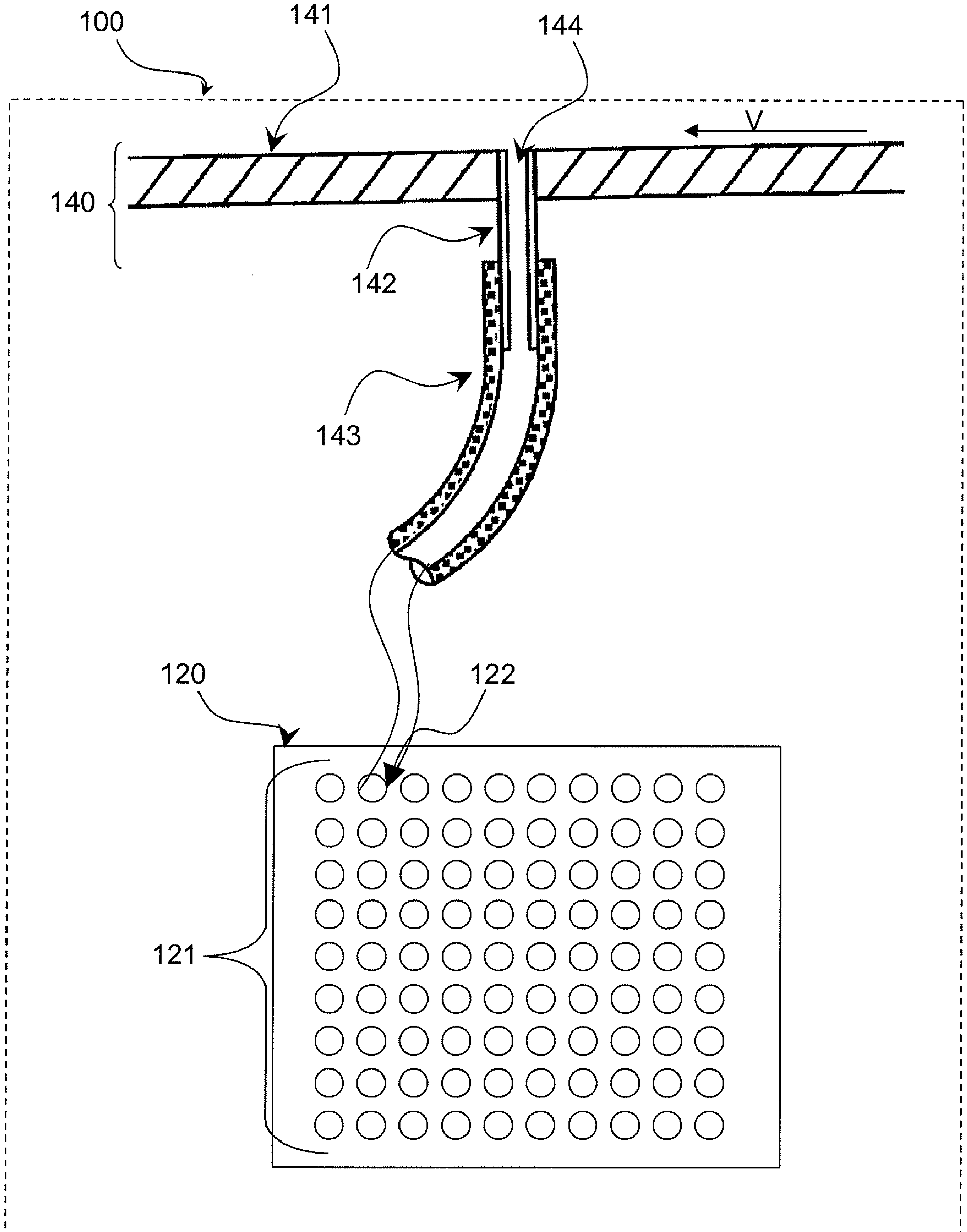


FIG. 1 (Prior Art)

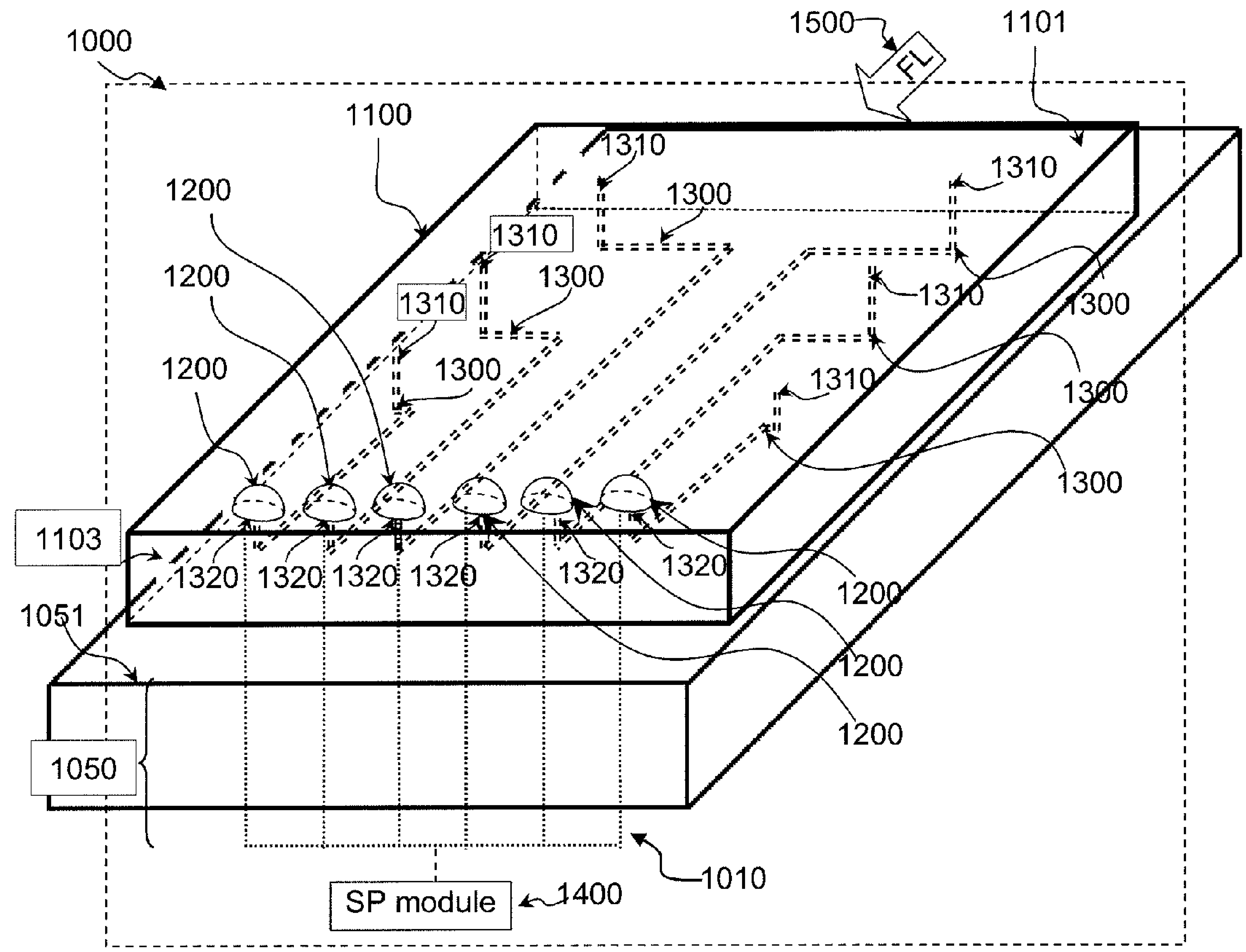

1000
1500
FL
1101
1100
1310
1300
1200
1310
1300
1310
1310
1300
1310
1300
1310
1300
1103
1320
1320
1320
1320
1320
1320
1200
1051
1200
1050
1200
SP module
1400
1010

FIG. 2A

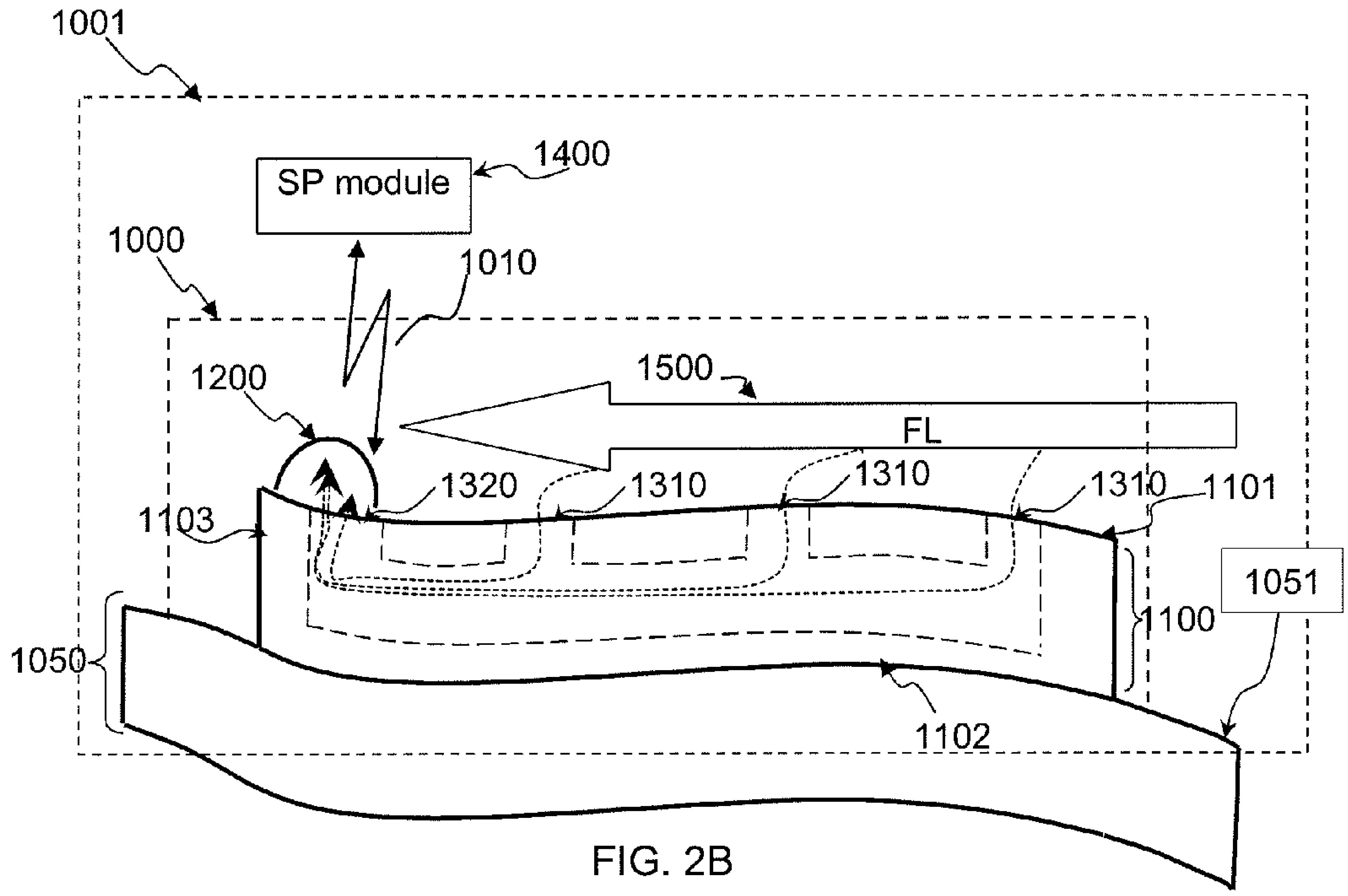

1001
SP module
1400
1000
1010
1500
1200
FL
1320
1310
1310
1310
1101
1103
1051
1100
1050
1102

FIG. 2B

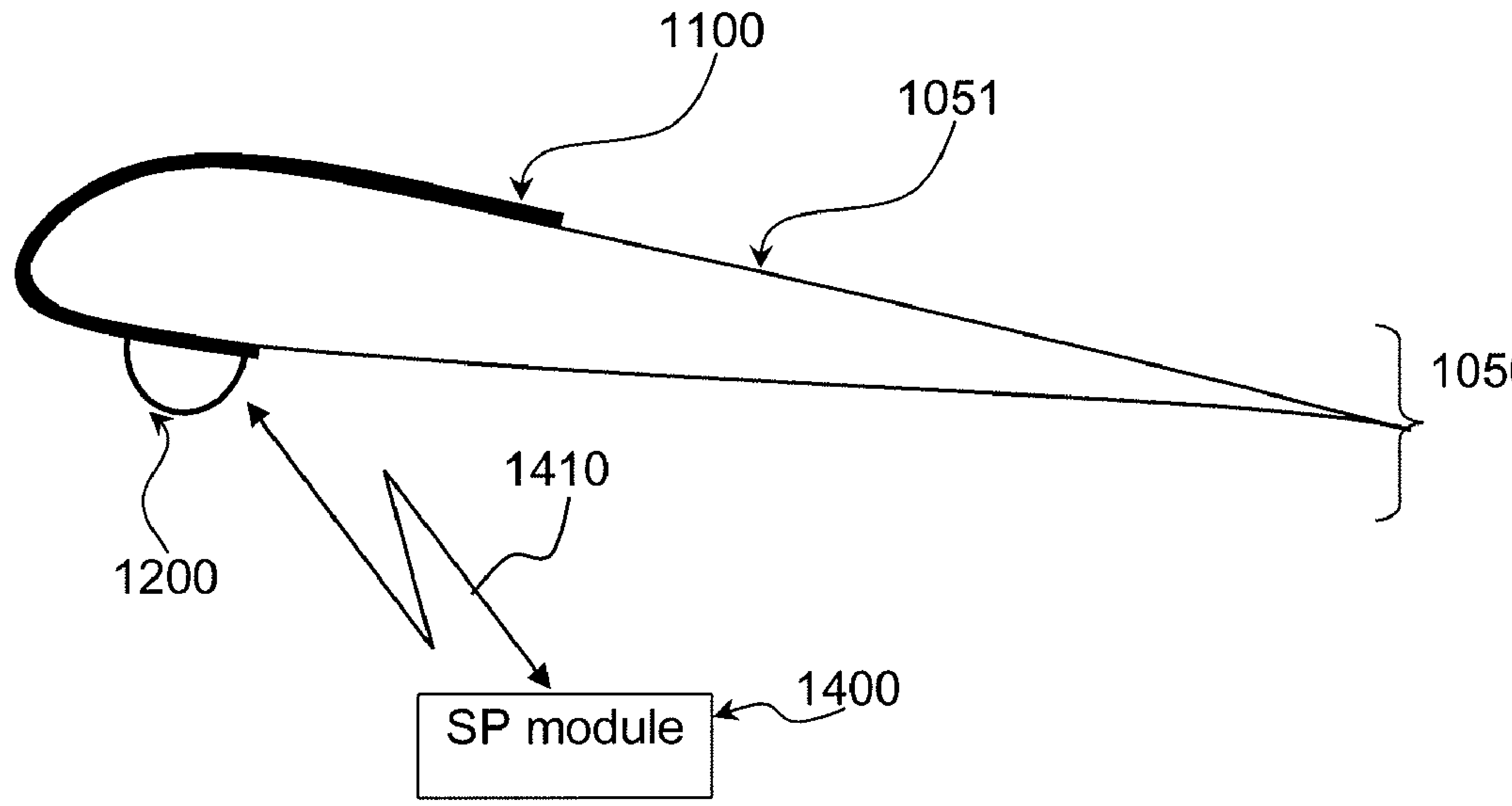

1100
1051
1050
1410
1200
SP module
1400

FIG. 3A

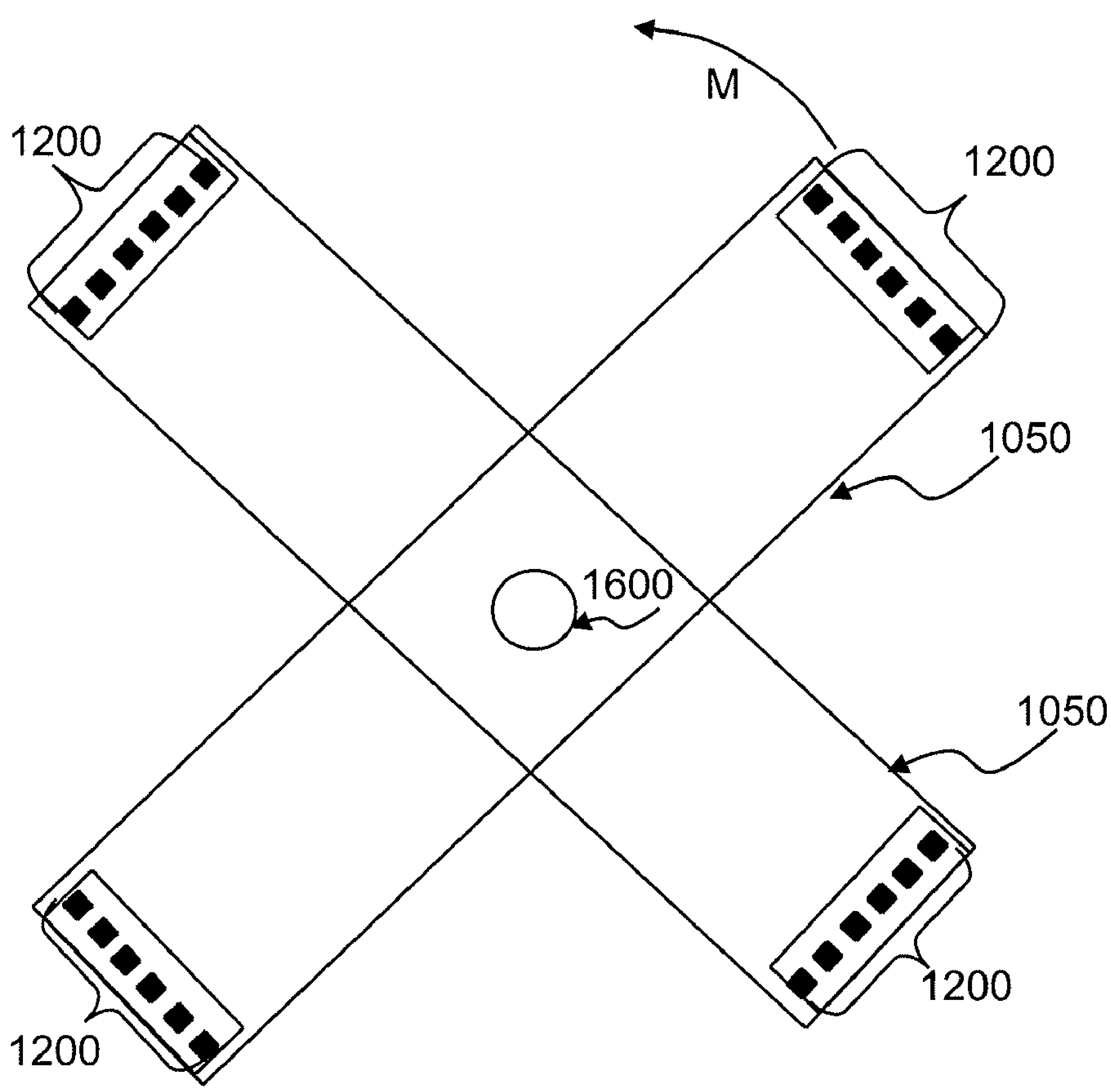

M
1200
1200
1050
1600
1050
1200
1200

FIG. 3B

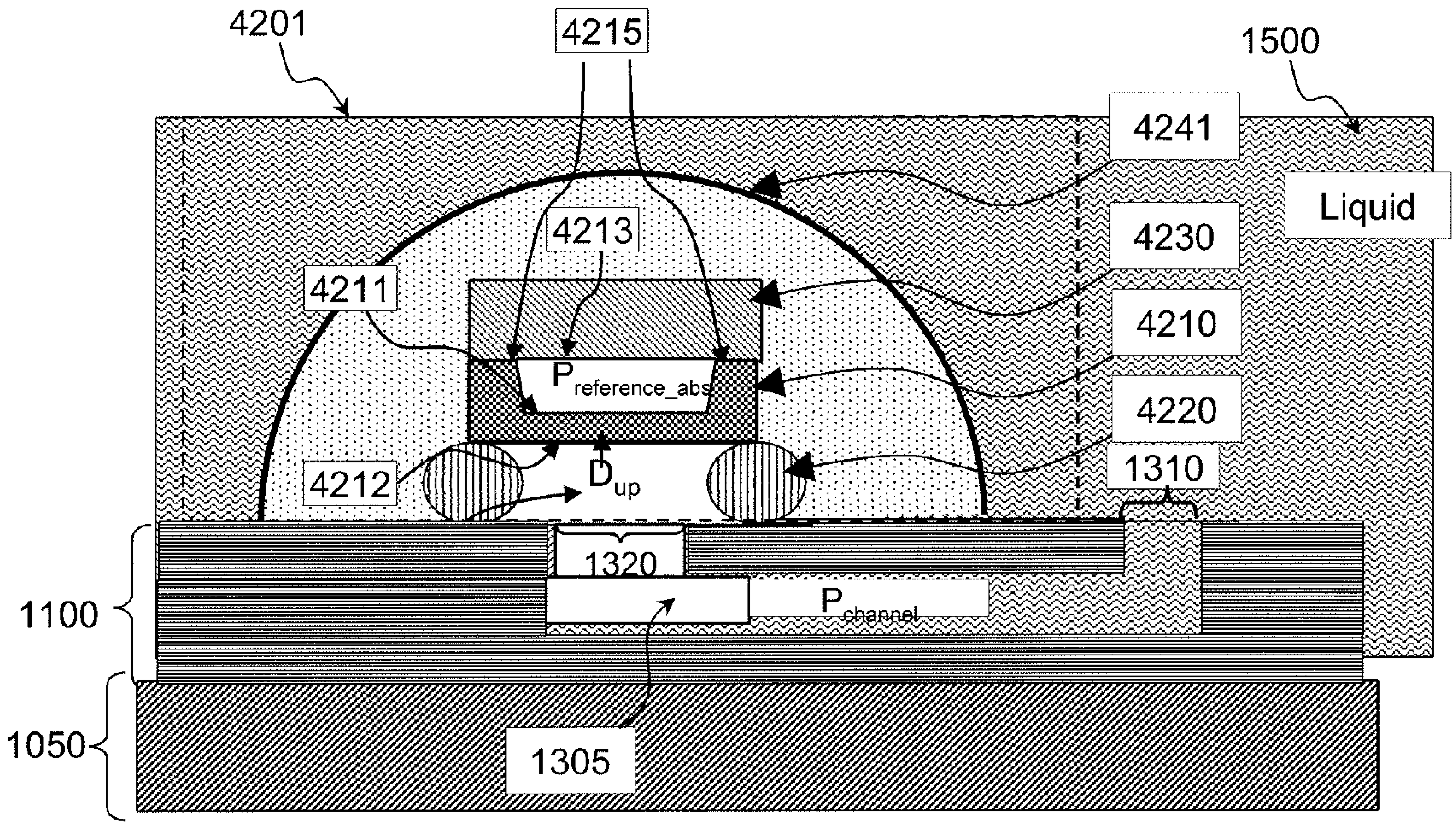

4201
4215
1500
4241
Liquid
4230
4213
4211
4210
$P_{reference\_abs}$
4220
4212
D_{up}
1310
1320
1100
$P_{channel}$
1050
1305

FIG. 4A

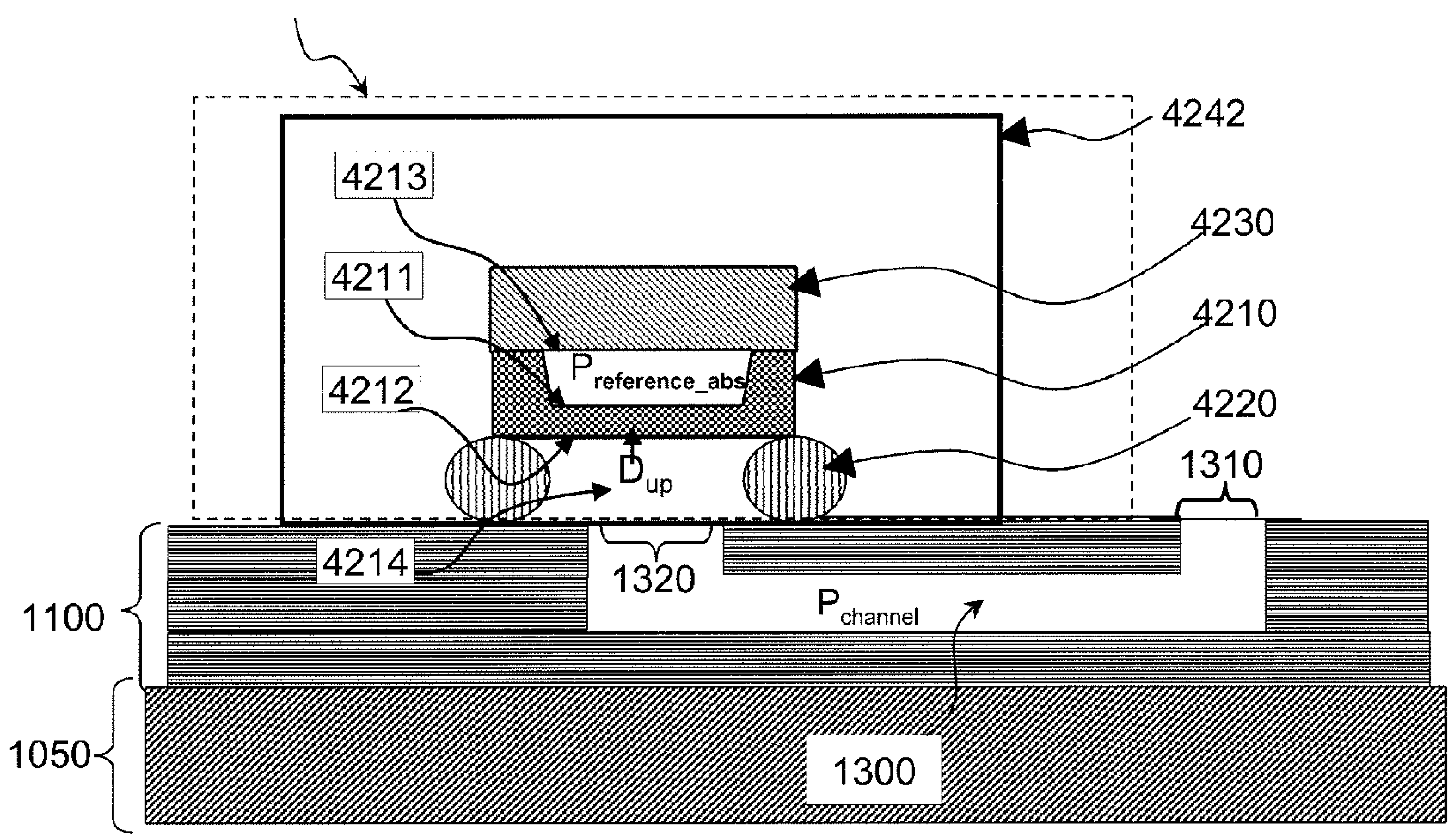

4242
4213
4230
4211
4210
$P_{reference\_abs}$
4212
4220
D_{up}
1310
4214
1320
1100
$P_{channel}$
1050
1300

FIG. 4B

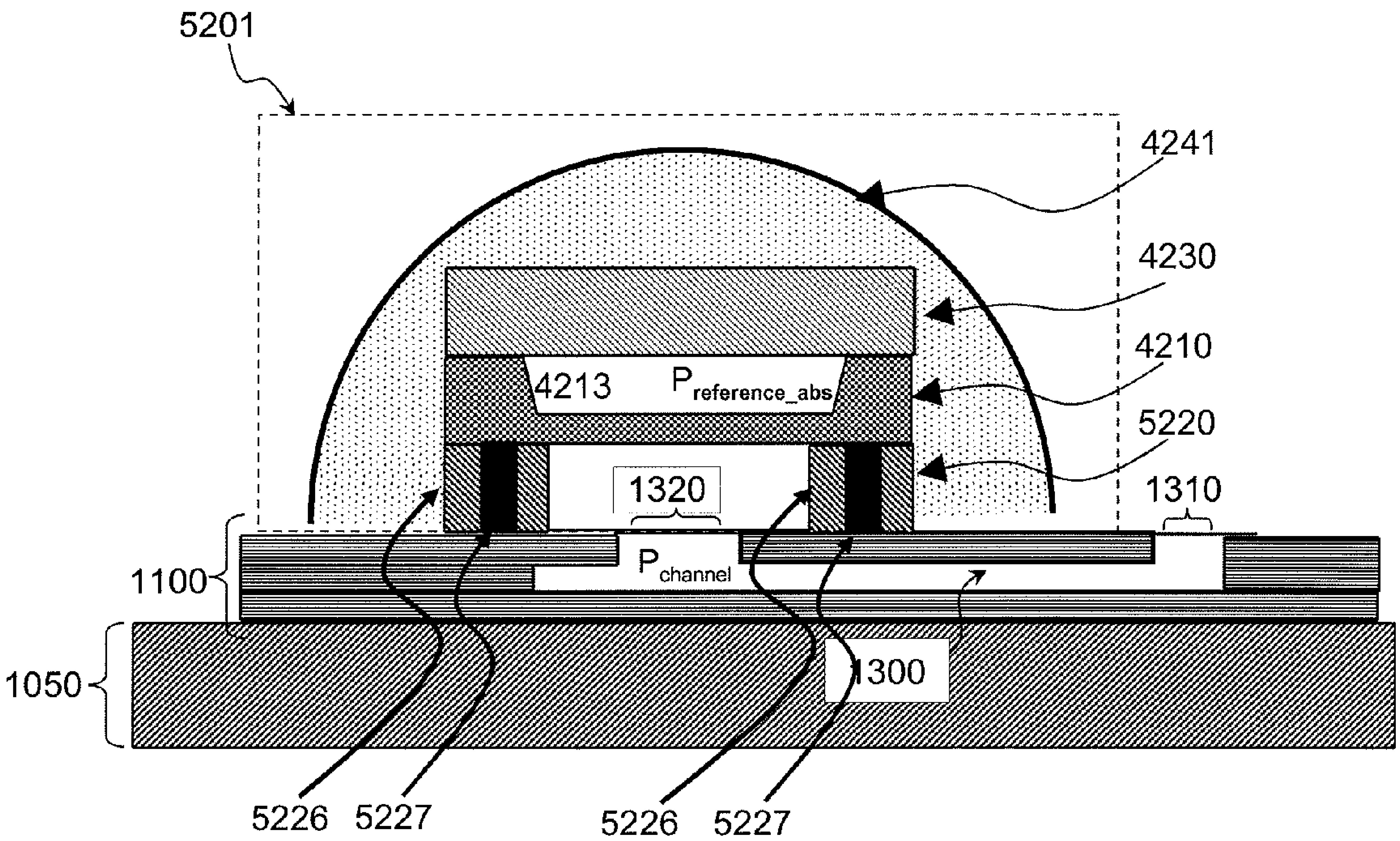

5201
4241
4230
4210
5220
4213
$P_{reference\_abs}$
1320
1310
1100
$P_{channel}$
1050
1300
5226
5227
5226
5227

FIG. 5A

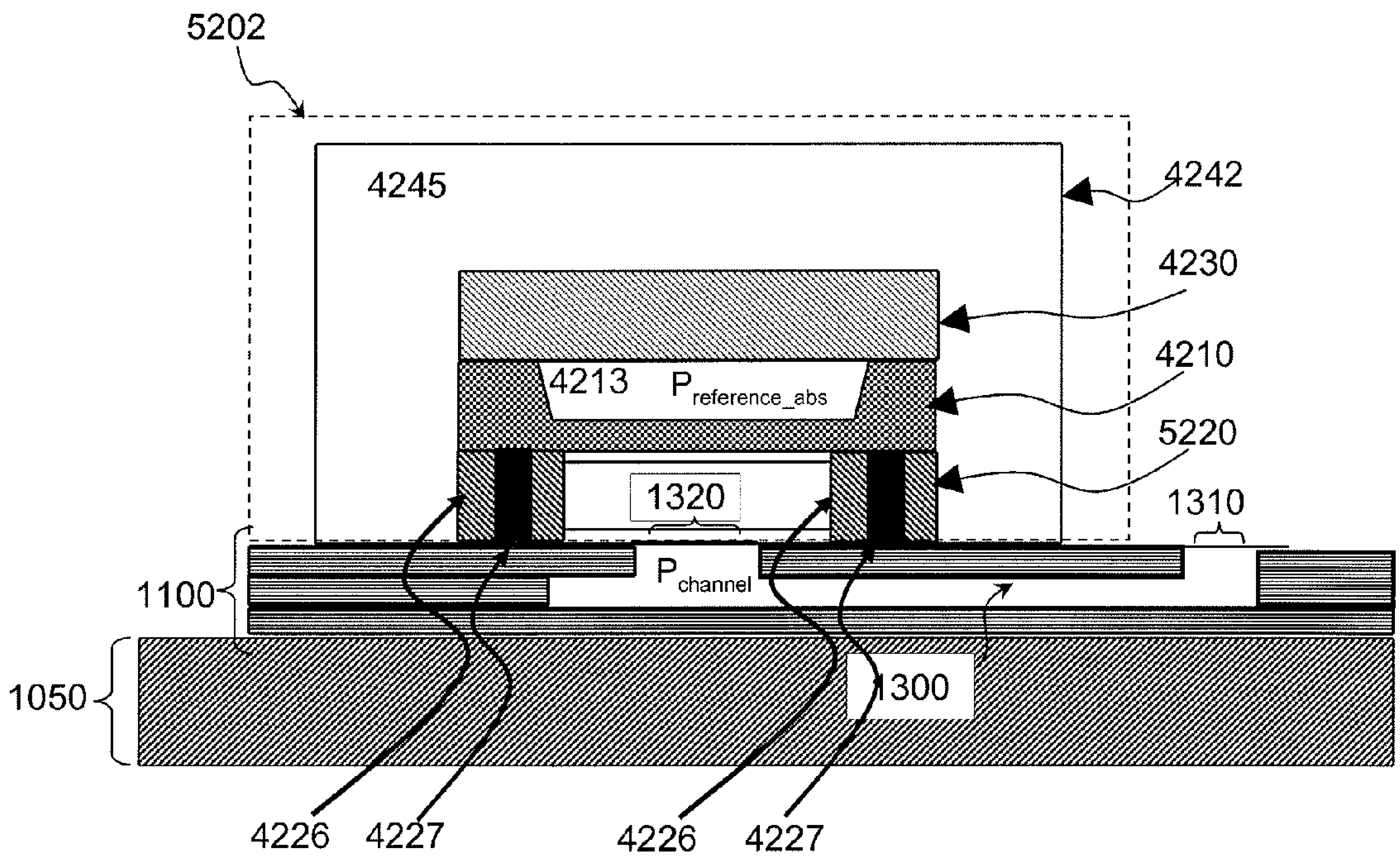

5202
4245
4242
4230
4210
5220
4213
$P_{reference\_abs}$
1320
1310
1100
$P_{channel}$
1050
1300
4226
4227
4226
4227

FIG. 5B

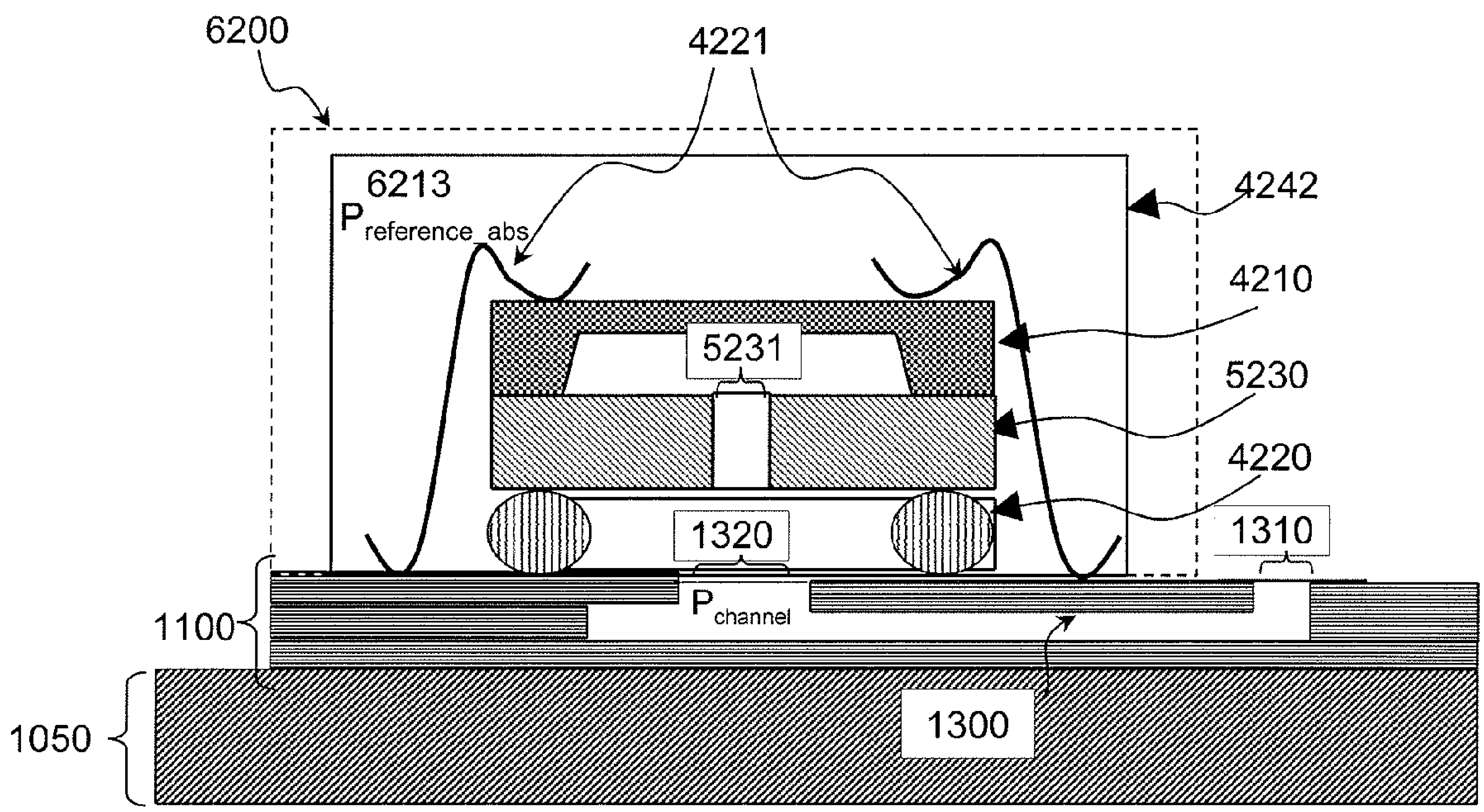

6200
4221
4242
6213
$P_{reference\_abs}$
4210
5231
5230
4220
1320
1310
1100
$P_{channel}$
1050
1300

FIG. 6

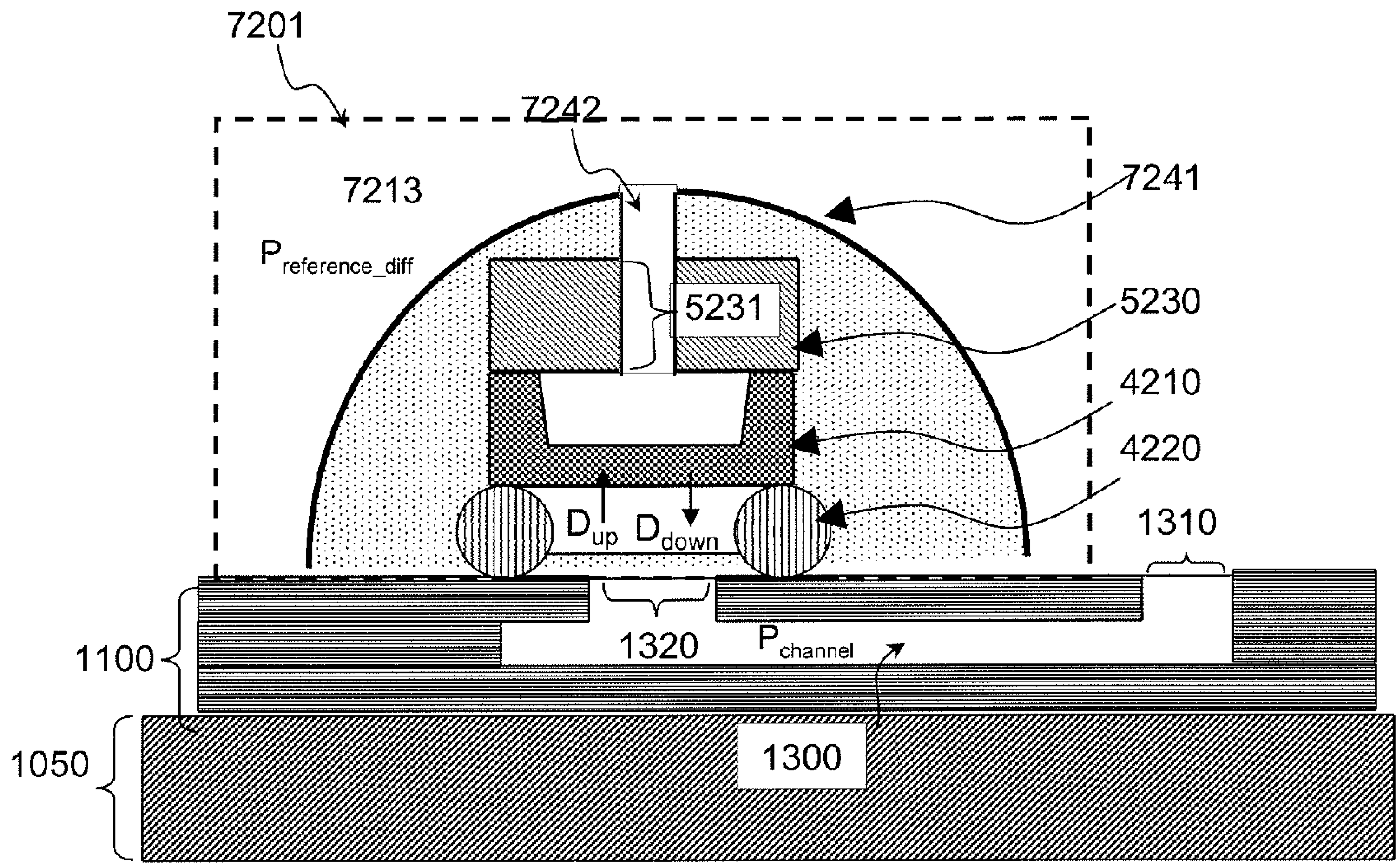

7201
7242
7213
$P_{reference\_diff}$
7241
5231
5230
4210
4220
D_{up} D_{down}
1310
1320
$P_{channel}$
1100
1050
1300

FIG. 7A

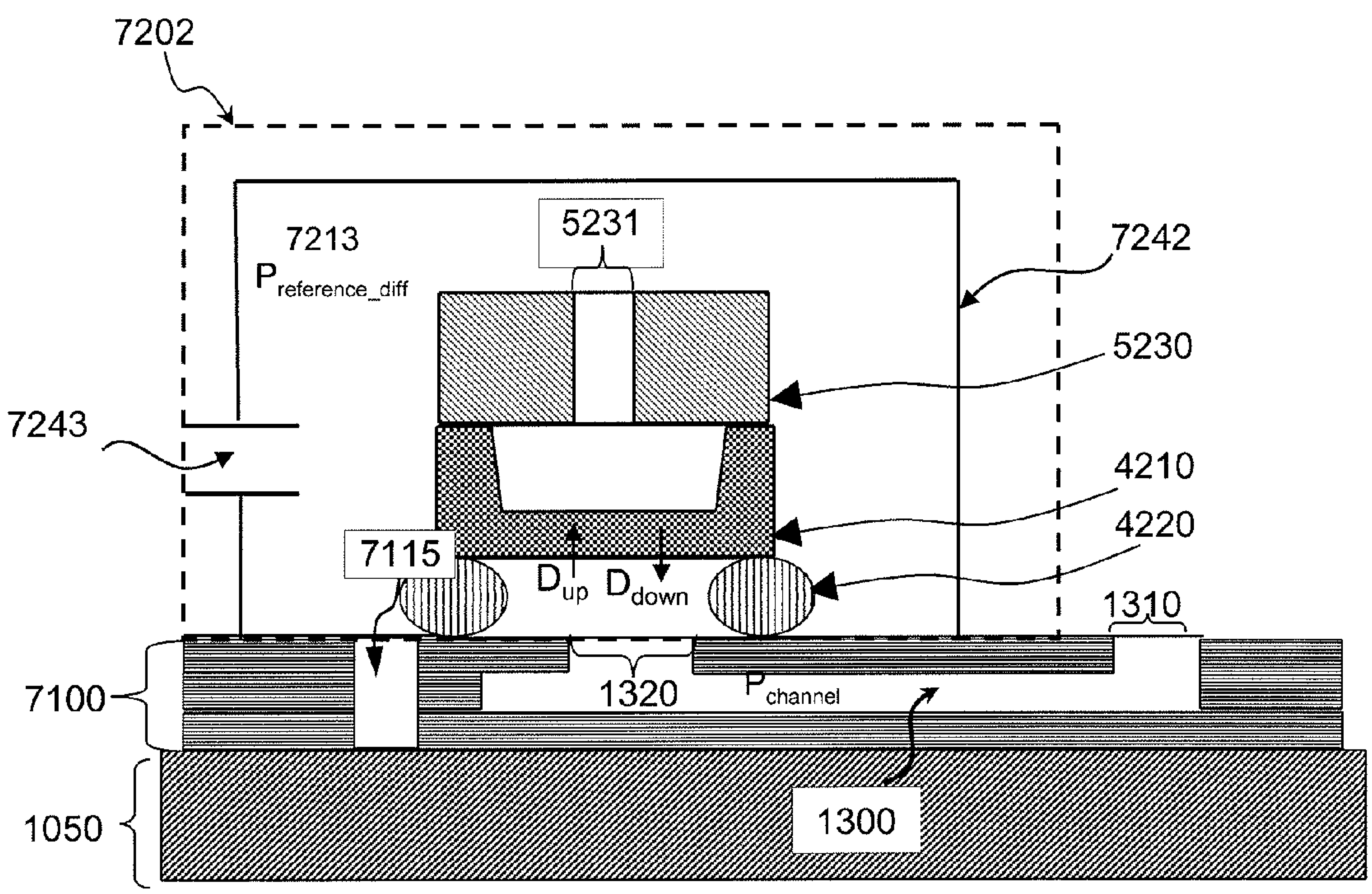

7202
5231
7242
7213
$P_{reference\_diff}$
5230
7243
4210
4220
7115
D_{up} D_{down}
1310
7100
1320
$P_{channel}$
1050
1300

FIG. 7B

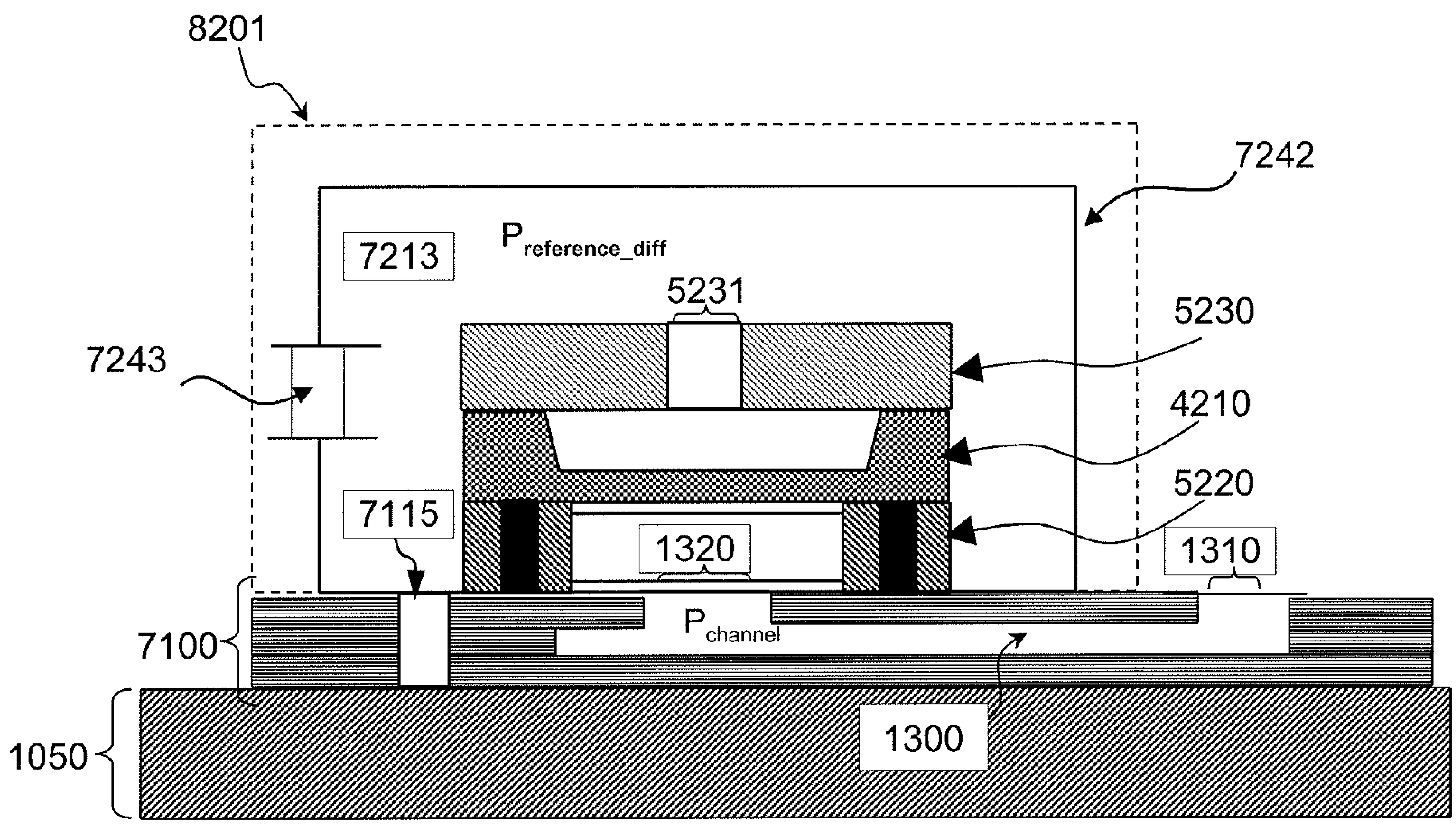

8201
7242
7213
$P_{reference\_diff}$
5231
5230
7243
4210
5220
7115
1320
1310
7100
$P_{channel}$
1050
1300

FIG. 8

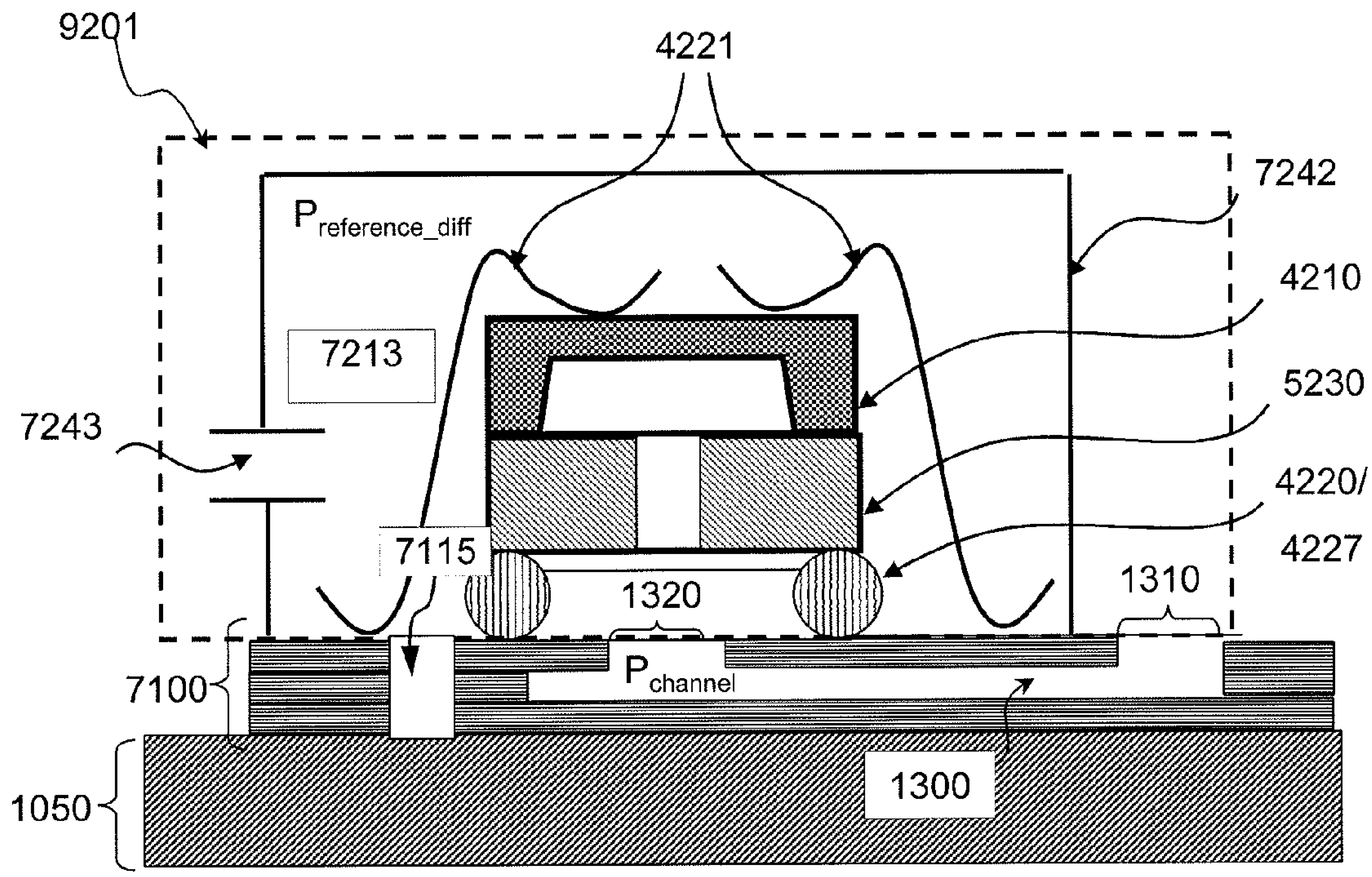

9201
4221
7242
$P_{reference\_diff}$
4210
7213
5230
7243
4220/
4227
7115
1320
1310
$P_{channel}$
7100
1300
1050

FIG. 9A

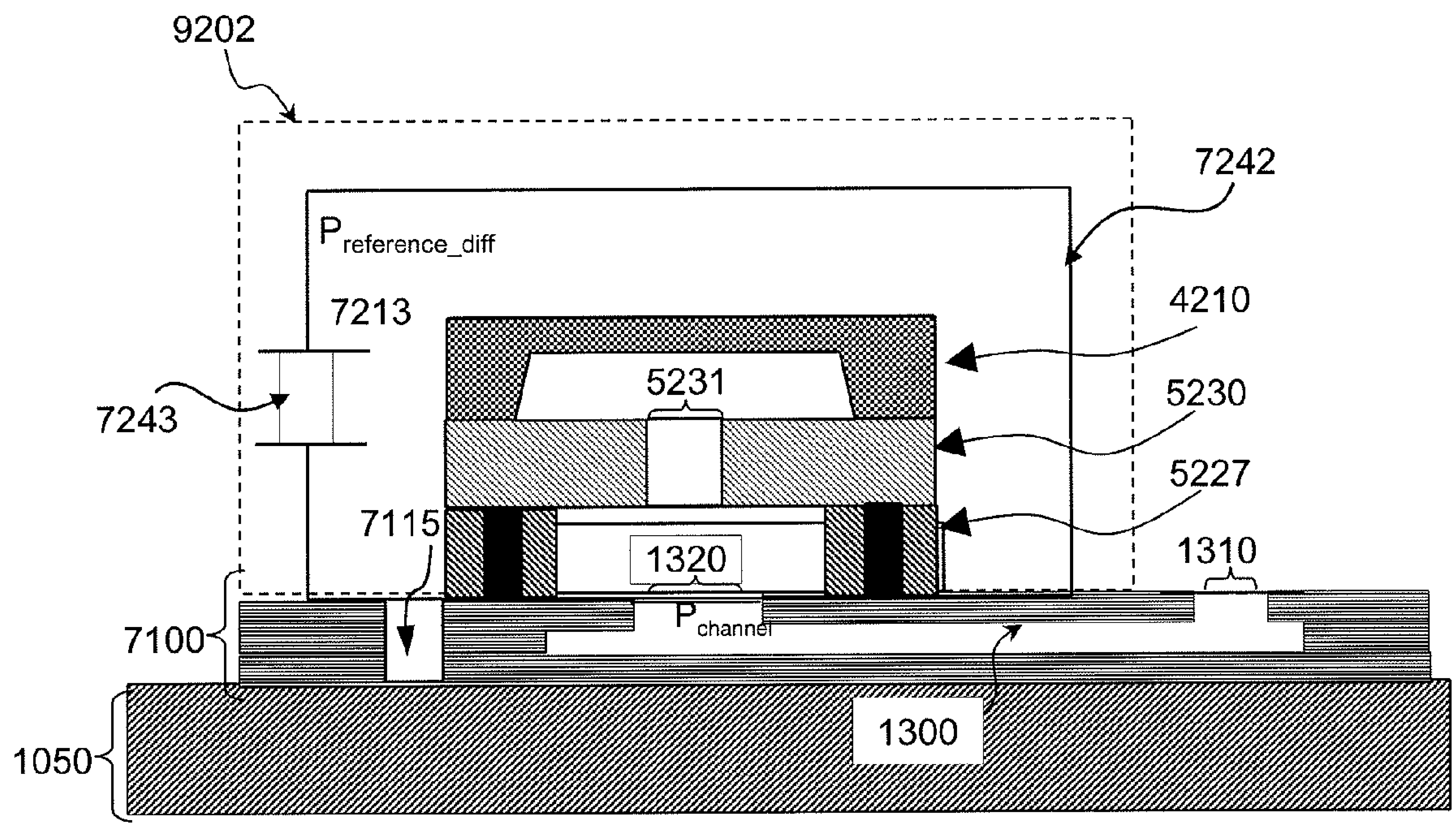

9202
7242
$P_{reference\_diff}$
4210
7213
5231
7243
5230
5227
7115
1320
1310
$P_{channel}$
7100
1300
1050

FIG. 9B

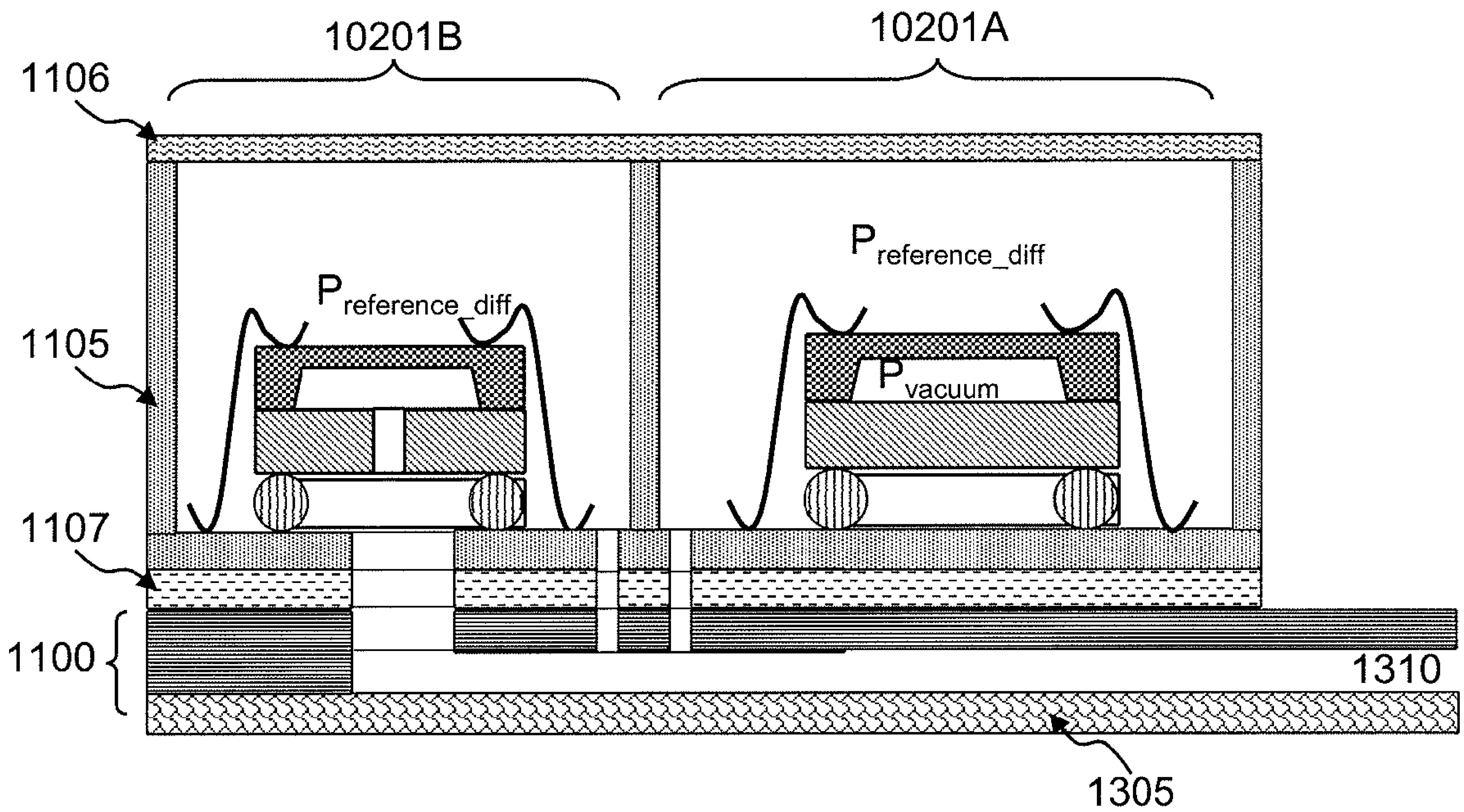


FIG. 10A

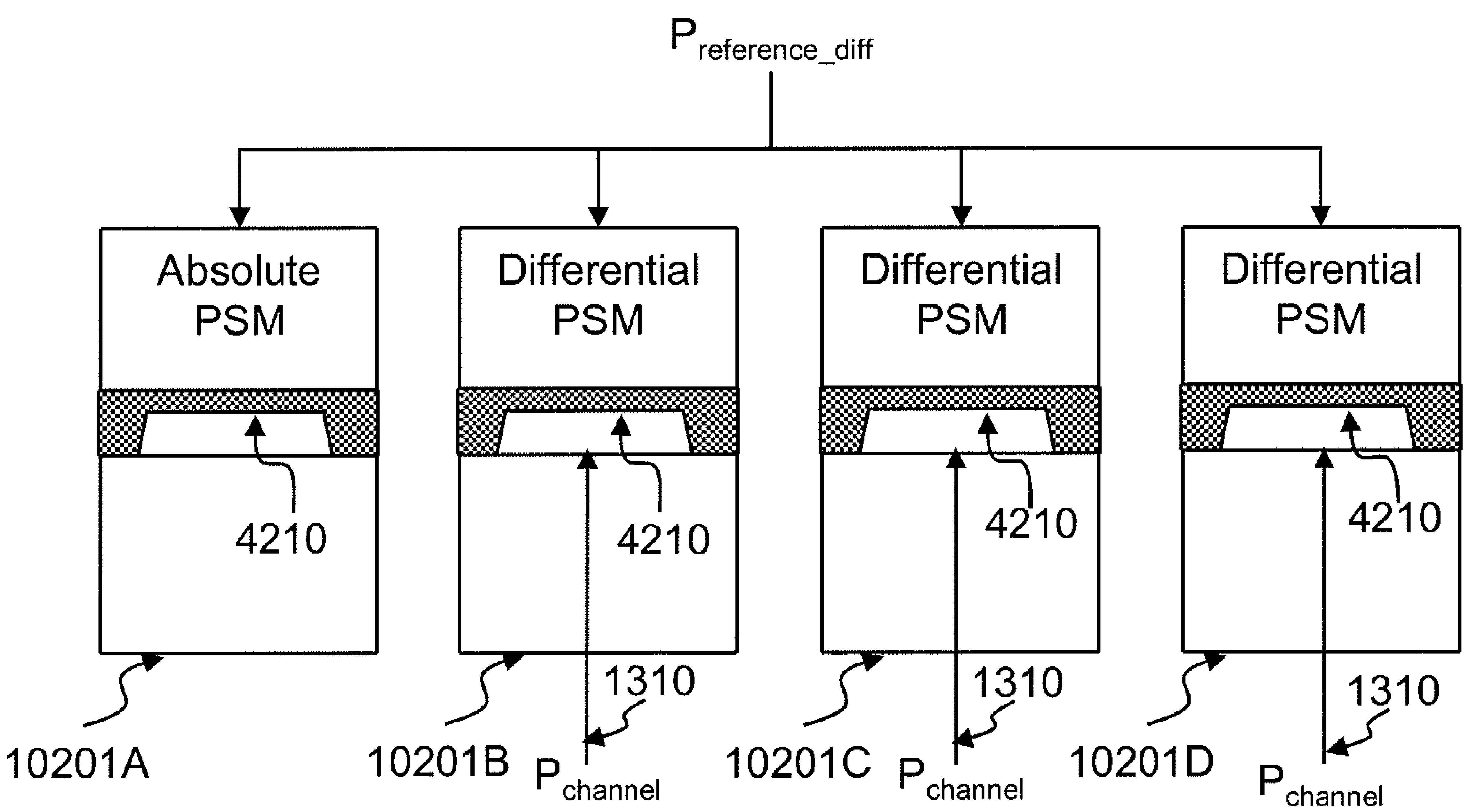


FIG. 10B

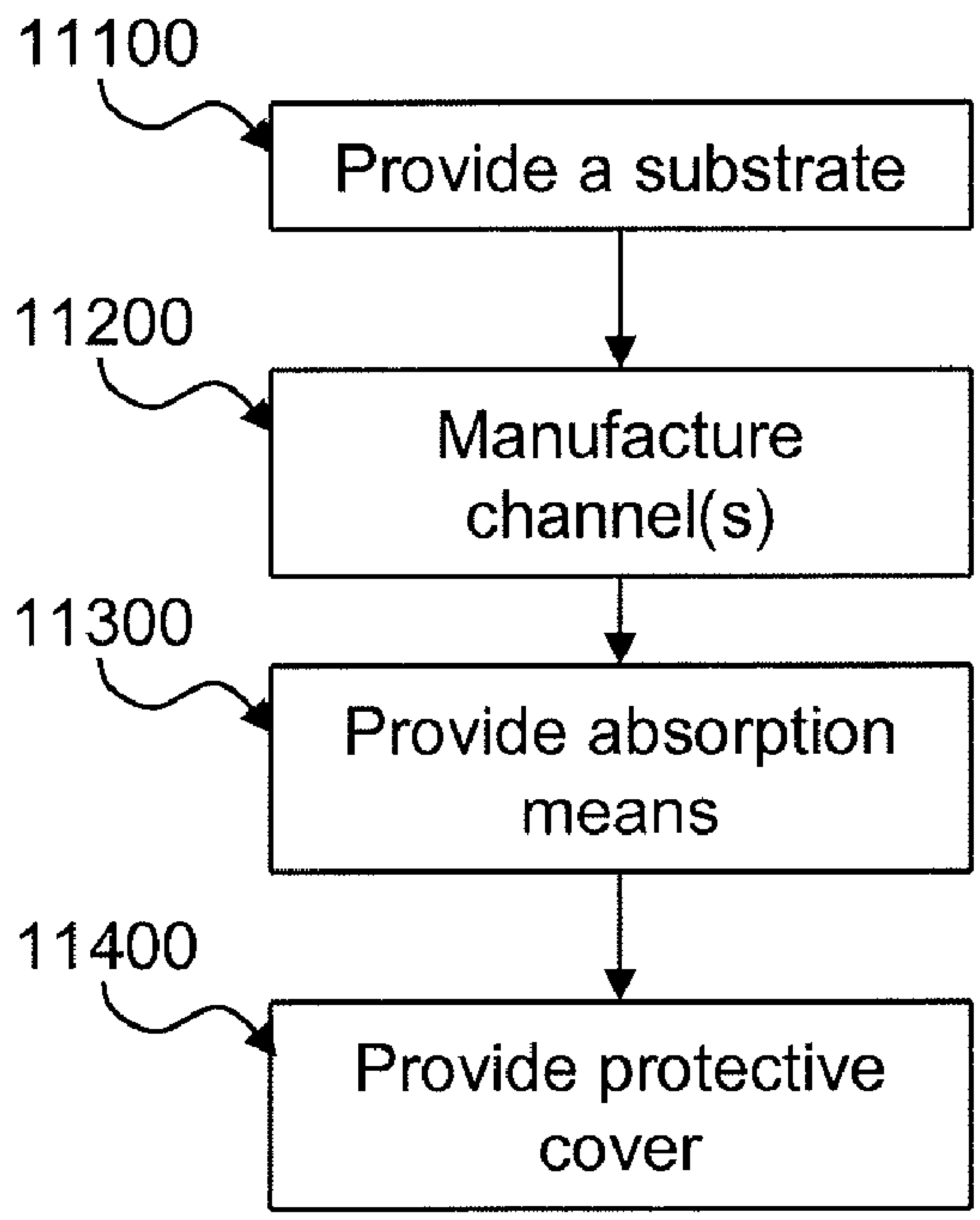


FIG. 11A

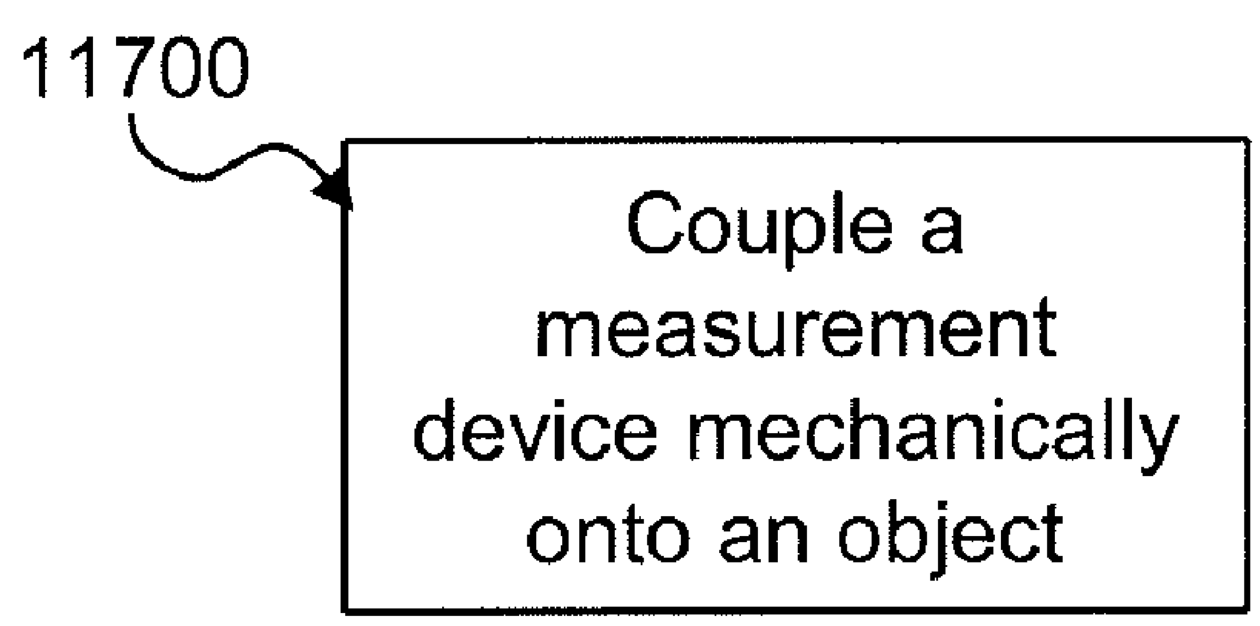


FIG. 11B

PRESSURE MEASUREMENT DEVICE AND SYSTEM, AND METHOD FOR MANUFACTURING AND USING THE SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

This patent application claims priority from U.S. Provisional Patent Application No. 60/907,013 filed on Mar. 16, 2007, the Application which is incorporated herein by reference in its entirety.

FIELD OF INVENTION

The present invention relates to the field of measurement of fluid characteristics and more specifically to the measurement of pressure exerted by fluids on a surface.

SUMMARY OF SOME EMBODIMENTS OF THE INVENTION

The present invention discloses inter alia, a pressure measurement device comprising: a substrate that includes at least one pressure sensing module and at least one fluid-conductive channel, wherein each channel has a first aperture and a second aperture. The substrate is flexible such that the pressure measurement device is conformably adjustable onto an object's surface. The first aperture is located on the substrate such that when the substrate is suitably adjusted onto the object's surface, the first aperture is open to the exterior of the object's surface. The pressure sensors module is operatively connected to at least one of the second apertures, such that the at least one pressure sensing module is generally being subjected to the pressure being present at the first aperture.

In embodiments of the invention, the first aperture is remotely located from the pressure measurement module.

In embodiments of the invention, the pressure sensing module comprises a membrane made of a piezo-responsive material.

In embodiments of the invention, the piezo-responsive material is either one a piezo-resistive and piezo-electric material.

In embodiments of the invention, the pressure sensing module is both one of an absolute pressure sensing module and a differential pressure sensing module.

In embodiments of the invention, the at least one channel has a diameter ranging between 0.05 and 0.5 mm.

In embodiments of the invention, the substrate has a thickness of less than 1 mm.

In embodiments of the invention, the pressure measurement device further comprises absorption means that are sandwiched between the substrate and either one the membrane and the interface unit to avoid generating stress in membrane generated due a difference in temperature-based expansion between membrane and substrate.

The present invention further discloses a pressure measurement system, comprising of a signal processing module; and a pressure measurement device that includes the at least one pressure sensing module, wherein the at least one pressure sensing module is operatively connected to said signal processing module by wire or wireless communication.

BRIEF DESCRIPTION OF THE DRAWINGS

These and further features and advantages of the invention will become more clearly understood in the light of the ensu-

ing description of a some embodiments thereof, given by way of example only, with reference to the accompanying figures, wherein:

FIG. **1** is a schematic cross-sectional side view illustration of a pressure measurement device and system as used in the art;

FIG. **2**A is schematic isometric illustration of a pressure measurement device and system, according to some embodiments of the invention, wherein the device is conformably adjusted on an object's surface;

FIG. **2**B is a schematic side view illustration of the pressure measurement device and system according to some embodiments of the invention, wherein the device is conformably adjusted on the object's surface;

FIG. **3**A is a schematic side view illustration of the pressure measurement device and system, wherein the device is conformably adjusted on a surface's object which is embodied by an airfoil;

FIG. **3**B is a schematic side view illustration of the pressure measurement device and system, wherein the device is conformably adjusted on the object's surface, and wherein the object is embodied by a rotatably coupled object;

FIG. **4**A is a detailed schematic cross-sectional side view illustration of an absolute pressure measurement device according to some embodiments of the invention, wherein the device is conformably adjusted on the surface's object and surrounded by a liquid fluid;

FIG. **4**B is a schematic cross-sectional side view illustration of an absolute pressure measurement device according to an alternative embodiment of the invention, wherein the device is adjusted on the surface's object;

FIG. **5**A is a schematic cross-sectional side view illustration of an absolute pressure measurement device according to an alternative embodiment of the invention, wherein the device is conformably adjusted on the surface of the object;

FIG. **5**B is a schematic cross-sectional side view illustration of an absolute pressure measurement device according to another embodiment of the invention, wherein the device is conformably adjusted on the surface of the object;

FIG. **6** is a schematic cross-sectional side view illustration of an absolute pressure measurement device according to a yet other embodiment of the invention, wherein the device is conformably adjusted on the surface of the object;

FIG. **7**A is a schematic cross-sectional side view illustration of a differential pressure measurement device, according to an embodiment of the invention, wherein the device is conformably adjusted on the surface of the object;

FIG. **7**B is a schematic cross-sectional side view illustration of a differential pressure measurement device, according to another embodiment of the invention, wherein the device is conformably adjusted on the surface of the object;

FIG. **8** is a schematic cross-sectional side view illustration of a differential pressure measurement device, according to an alternative embodiment of the invention, wherein the device is conformably adjusted on the surface of the object;

FIG. **9**A is a schematic cross-sectional side view illustration of a differential pressure measurement device according to a yet other embodiment of the invention, wherein device is conformably adjusted on the surface of the object;

FIG. **9**B is a schematic cross-sectional side view illustration of a differential pressure measurement device according to a yet alternative embodiment of the invention, wherein the device is conformably adjusted on the surface of the object;

FIG. **10**A is a schematic cross-sectional side view illustration of a pressure measurement device according to an embodiment of the invention;

FIG. 10B is a schematic block-diagram illustration of the pressure measurement device of FIG. 10A;

FIG. 11A is a flow-chart illustration of a method for manufacturing the pressure measurement device according to an embodiment of the invention; and.

FIG. 11B is a flow-chart illustration of a method according to an embodiment of the invention, for using the pressure measurement device and system.

The drawings taken with description make apparent to those skilled in the art how the invention may be embodied in practice.

It will be appreciated that for simplicity and clarity of illustration, elements shown in the figures have not necessarily been drawn to scale. For example, the dimensions of some of the elements may be exaggerated relative to other elements for clarity. Further, where considered appropriate, reference numerals may be repeated among the figures to indicate identical and analogous elements but may not be referenced in the description for all figures.

BACKGROUND OF INVENTION

Pressure sensors are widely used for the analysis and monitoring of the pressure distribution on an object's surface subjected to the flow of fluid such as liquid and/or gas. For example, pressure sensors may be adjusted on an aircraft's airfoil to provide the pilot or manufacturer of the same aircraft with information about the airfoil's pressure distribution for monitoring and analysis. Moreover, pressure sensors can be used as an engineering tool to optimize the aerodynamic and/or hydrodynamic properties of an object's surface according to predetermined criteria. For example, information received from the pressure sensors arranged on a vehicle may be analyzed to derive the drag exerted by, e.g., air, on the vehicle in motion, and in particular, to determine which areas of the vehicle's surface are subjected to the highest drag and should therefore be reshaped to lower the vehicle's drag below a predetermined threshold value.

It should be noted that the pressure measured by such a pressure sensor may be the equivalent of the sum of dynamic pressure and/or static pressure acting on the object's surface.

Pressures measurement devices and systems as used in the art are outlined hereinafter. With reference to FIG. **1**, a pressure measurement device and system **100** as used in the art includes a pressure transducer unit **120** comprising an array of pressure transducers **121** to measure the pressure a fluid exerts on a surface **141** of an object **140**. To enable the measurement of the pressure, object **140** comprises measuring taps **142**, to which at least some of the pressure transducers **121** are respectively coupled via a tube **143**, which are pressed and/or glued or otherwise fixedly inserted into holes **144**. Some of the fluid flowing over surface **141** exerts dynamic pressure thereon and engages therefore with measuring taps **142**. Consequently, some fluid flows through the respective tubes **143** towards the corresponding member **122** of the transducer array **121** and exerts a pressure on the pressure sensor which is operatively coupled to member **122**. The pressure exhibited by the fluid on the pressure sensor of member **122** depends, inter alia, on the velocity of the fluid, which is schematically indicated with arrow "V", flowing over surface **141**. As is known from thermodynamics, an increase in fluid velocity may for example result in a expansion of the fluid flowing over surface **141** (a physical phenomenon described, e.g., by means of the Bernoulli equation), whereby the increase in expansion may result in a decrease of the pressure exerted by the fluid in tube **143** and thus on the respective pressure sensor of transducer member **122**. In the art, a pressure transducer unit **110** may be embodied by a single pressure transducer (not shown) which is operatively couplable to measuring tap **142** for the measurement of pressure on surface **141** on the respective location. The outer diameter of tubes **143** might be around 2 mm, whereas taps **142** may have an outer diameter of approx. 1 mm. The diameter of the channel of tap **142** can be as small 0.1 mm. Other pressure measurement devices as used in the art are outlined hereinafter.

U.S. Pat. No. 5,359,887, which is incorporated herein by reference in its entirety, discloses a coating material for wind tunnel luminescent barometry of surfaces such as airfoils and airframes uses a resin such as poly[1-(trimethylsilyl)propyne], or a siloxane polymer, to carry a pressure indicator. The pressure indicator may be photoluminescent ruthenium complex, such as [Ru(Ph2phen)2]Cl2, a photoluminescent platinum complex, such as PtOEP, and photoluminescent mixtures of pyrene and perylene.

U.S. Pat. No. 5,983,727, which is incorporated herein by reference in its entirety, discloses a fluid pressure sensor/sensor array having a substantially incompressible mounting structure with a cavity formed therein. An elastic membrane is attached to said mounting structure and across said cavity, separating the cavity from the fluid to be measured. At least one non-contact transducer is attached to the mounting structure in the cavity to detect deflection at a selected plurality of regions on the membrane. The sensitivity and pressure range of the sensor can be chosen by preselecting the elasticity of the membrane, stretching the membrane across the cavity under a preselected tension, maintaining a predetermined reference pressure in the cavity, and/or actively controlling the membrane tension. For a pressure sensor array, there are at least two fluid pressure sensors, where at least one sensor is of the type described herein. A sensor array can also be formed by multiple cavities within a single mounting structure.

U.S. Pat. No. 6,662,647, which is incorporated herein by reference in its entirety, discloses a gaseous fluid data sensor assembly for acquiring data regarding the ambient environment adjacent a surface of an airframe with adjacent air speeds below 40 knots (or another aerodynamic structure with low speed gaseous fluid flow adjacent thereto) having a flexible substrate adhesively conforming to the airframe surface, a conformable cover layer and a relatively thin air data sensor for measuring air pressure between the substrate and the cover layer. The assembly also includes a fiber optic communication link, a battery, a data acquisition subsystem, and a flexible printed circuit, all between the substrate and the cover layer. The cover layer is formed of a polymer film.

U.S. Pat. No. 6,826,968, which is incorporated herein by reference in its entirety, discloses a device for detecting the pressure exerted at different points of a flexible and/or pliable object that may assume different shapes. The device includes a plurality of capacitive pressure sensors and at least a system for biasing and reading the capacitance of the sensors. The requirements of flexibility or pliability are satisfied by capacitive pressure sensors formed by two orthogonal sets of parallel or substantially parallel electrodes spaced, at least at each crossing between an electrode of one set and an electrode of the other set, by an elastically compressible dielectric, forming an array of pressure sensing pixel capacitors. The system for biasing and reading the capacitance includes column plate electrode selection circuits and row plate electrode selection circuits and a logic circuit for sequentially scanning the pixel capacitors and outputting pixel values of the pressure for reconstructing a distribution map of the pressure over the area of the array.

U.S. Pat. No. 7,127,948, which is incorporated herein by reference in its entirety, discloses a sensor, sensory array, and associated method for measuring a pressure, wherein the sensor includes a piezoelectric sensory device that is disposed on an electrically insulative substrate that can be adhered to a member for measuring the pressure on the member. The piezoelectric sensory device defines first and second contact surfaces and is adapted to provide an electric potential between the surfaces that corresponds to a pressure on the piezoelectric sensory device. Conductive terminals are in electrical communication with the piezoelectric sensory device and therefore also provide the electric potential indicative of the pressure on the surface of the test member. An electrically insulative sheet is disposed opposite the piezoelectric sensory device from the substrate. An electronic monitoring device can be electrically connected to the piezoelectric sensory device via the terminals and configured to monitor the electric potential provided by the piezoelectric sensory device.

Xiao et al. describe in "A Pressure Sensor Using Flip-Chip on Low-Cost Flexible Substrate", published in IEEE 2001 Electronic Components and Technology Conference, which is incorporated herein by reference in its entirety, a pressure sensor and an actuator which were assembled on a flexible substrate using FCOF technology, and a photolithography process allegedly meeting the solder bump fabrication requirement of the sensor chip.

DESCRIPTION OF SOME EMBODIMENTS OF THE INVENTION

It is the object of the present invention to provide an alternative device, system and method for measuring the pressure exerted on an object's surface by a fluid. The device and system are hereinafter referred to as "pressure measurement device" and "pressure measurement system", respectively. The pressure measurement device according to an embodiment of the invention comprises a substrate, which may be flexible, bendable lightweight. The device may for example, weigh less than 10 grams. Thusly configured, the device may be conformably adjustable onto an object's surface.

The substrate may include one or more fluid-conductive channels, each of which may have a first and a second aperture, wherein the channels may be micro-sized.

A pressure sensing module (PSM) is provided on the substrate such that the PSM is operatively connected to the second aperture, i.e., the second aperture may be open to and terminate in the PSM. In some embodiments, the first and the second aperture may be remotely located from each other. Correspondingly, a respective PSM may be remotely located from the first aperture and therefore from the location for which the pressure is being measured by for example, at least 10 cm. The device is configured such that when it is suitable adjusted onto an object's surface, the first aperture of such a channel is open in direction to the exterior of the object's surface layer. Thusly adjusted, at least some fluid surrounding the object may flow through such a first aperture, and via the respective channel to the second aperture that terminates in the PSM. Therefore, the pressure exerted by the fluid on the location of the first aperture is measured by the corresponding PSM. The substrate may have a thickness of, e.g., less than 1 mm. Moreover, the substrate has a planar-like extent and may cover a surface area ranging from a few square centimeters to a few square meters and may for example cover a surface area of approximately 20 mm*180 mm. The PSM may cover an area of, for example, approximately 20 mm*25 mm and may have a thickness of, e.g., less than 3 mm.

The pressure measurement device may additionally include a signal processing (SP) module that is responsively coupled to at least some of the PSMs. The SP module may have a thickness of e.g., less than 10 mm.

The substrate thus enables large-area covering of at least some part of an object's surface. Accordingly, the pressure measurement device enables the measurement of pressure distribution of a large area (for e.g. stall detection on airfoils). Since the substrate may be flexible and/or cover large areas and/or may have a relatively low mass, the pressure measurement device may be detachably coupleable on large surface areas by employing low-force coupling means, and is thus easily repositionable. Such coupling means may be, for example, glues employing low-adhesive forces of about less than about 500 grams per cm between two materials.

Objects on which the pressure measurement device is conformably adjustable include but are not limited to wind tunnel facilities, wings, propellers, fans, turbo-machinery, turbine blades, airfoils, aquafoils, vehicles (e.g. race cars, trains), aircrafts (e.g. engineless aircraft, glider, fighter plane, passenger plane, unmanned aerial vehicles), sails, maritime vessels (e.g., sail ships, motorboats, warships, submarines), rockets, missiles, watercrafts, helmets, surfing boards, bob sleds, sportswear, piping systems, ventilation systems, air conditioning systems, compressors, valves, pumps, blowers (e.g. vacuum cleaners, leaf blowers, hair dryers), hydropower generators and hydropropulsion equipment.

In addition, by conforming pressure measurement device closely to the contour of an object to which it is attached, there may be minimal or even negligible effect on the liquid flow characteristics (e.g. pressure) in the object's surface layer being sensed.

It should be understood that an embodiment is an example or implementation of the inventions. The various appearances of "one embodiment," "an embodiment" or "some embodiments" do not necessarily all refer to the same embodiments.

Although various features of the invention may be described in the context of a single embodiment, the features may also be provided separately or in any suitable combination. Conversely, although the invention may be described herein in the context of separate embodiments for clarity, the invention may also be implemented in a single embodiment.

Reference in the specification to "one embodiment", "an embodiment", "some embodiments" or "other embodiments" means that a particular feature, structure, or characteristic described in connection with the embodiments is included in at least one embodiment, but not necessarily all embodiments, of the inventions.

It should be understood that the phraseology and terminology employed herein is not to be construed as limiting and is for descriptive purpose only.

The principles and uses of the teachings of the present invention may be better understood with reference to the accompanying description, figures and examples.

It should be understood that the details set forth herein do not construe a limitation to an application of the invention. Furthermore, it should be understood that the invention can be carried out or practiced in various ways and that the invention can be implemented in embodiments other than the ones outlined in the description below.

It should be understood that the terms "including", "comprising", "consisting" and grammatical variants thereof do not preclude the addition of one or more components, features, steps, integers or groups thereof.

Any publications, including patents, patent applications and articles, referenced or mentioned in this specification are herein incorporated in their entirety into the specification, to the same extent as if each individual publication was specifically and individually indicated to be incorporated herein. In addition, citation or identification of any reference in the description of some embodiments of the invention shall not be construed as an admission that such reference is available as prior art to the present invention.

The terms "right", "left", "bottom", "below", "lowered", "low", "top", "above", "elevated", "high", "vertical" and "horizontal" as well as grammatical variations thereof as used herein do not necessarily indicate that, for example, a "bottom" component is below a "top" component, or that a component that is "below" is indeed "below" another component or that a component that is "above" is indeed "above" another component as such directions, components or both may be flipped, rotated, moved in space, placed in a diagonal orientation or position, placed horizontally or vertically, or similarly modified. Accordingly, it will be appreciated that the terms "bottom", "below", "top" and "above" may be used herein for exemplary purposes only, to illustrate the relative positioning or placement of certain components, to indicate a first and a second component or to do both.

Although some demonstrative embodiments of the invention are not limited in this regard, discussions utilizing terms such as, for example, "processing," "computing," "calculating," "determining," "establishing", "analyzing", "checking", "identifying" or the like, may refer to operation(s) and/or process(es) of a computer, a computing platform, a computing system, or other electronic computing device, that manipulate and/or transform data represented as physical (e.g., electronic) quantities within the computer's registers and/or memories into other data similarly represented as physical quantities within the computer's registers and/or memories or other information storage medium that may store instructions to execute operations and/or processes and/or applications.

It should be understood that where the claims or specification refer to "a" or "an" element, such reference is not to be construed as there being only one of that element.

It should be understood that where the specification states that a component, feature, structure, or characteristic "may", "might", "can" or "could" be included, that particular component, feature, structure, or characteristic is not required to be included.

Where applicable, although state diagrams, flow diagrams or both may be used to describe embodiments, the invention is not limited to those diagrams or to the corresponding descriptions. For example, flow need not move through each illustrated box or state, or in exactly the same order as illustrated and described.

The term "method" refers to manners, means, techniques and procedures for accomplishing a given task including, but is not limited to those manners, means, techniques and procedures either known to, or readily developed from known manners, means, techniques and procedures by practitioners of the art to which the invention belongs.

The descriptions, examples, methods and materials presented in the claims and the specification are not to be construed as limiting but rather as illustrative only.

Meanings of technical and scientific terms used herein ought to be commonly understood as by one of ordinary skill in the art to which the invention belongs, unless otherwise defined.

The present invention can be implemented in the testing or practice with methods and materials equivalent or similar to those described herein.

Reference is now made to FIG. **2**A, FIG. **2**B and FIG. **3**A. According to some embodiments of the invention, a pressure measurement device **1000** includes a substrate **1100**, which may be flexible or bendable and which has an upper and lower boundary **1101** and **1102**, respectively. Substrate **1100** includes one or more channels **1300** each having a first aperture **1310** and a second aperture **1320**. First apertures **1310** may be open towards the exterior of substrate's **1100** boundary, whereas second apertures **1320** of respective channels **1300** may be open towards and terminate in corresponding PSMs **1200**. In some embodiments, first apertures **1310** may be remotely located from second apertures **1320**. Accordingly, PSMs **1200** may be located remotely from first aperture **1310** by, e.g., a few centimeters. Thusly configured, PSMs **1200** may not disturb the flow of fluid over first aperture(s) **1310**.

First apertures **1310** may be formed in substrate **1100** in accordance to various patterns such as, for example, a n*n matrix of first apertures **1310**. FIG. **2**A for example schematically illustrates a 2*3 matrix of first apertures **1310** arranged on substrate **1100**. In some embodiments of the invention, numerous first apertures **1310** may be crowded closely together for the measurement of pressure exerted onto a given location, thereby providing redundancy for the pressure measurement of said given location in case that one or more channels respective to said first apertures **1310** are blocked. According to some embodiments of the invention, for both the measurement of gasesous and liquid fluids, the diameter of channels **1300** may range, for example, from 0.05 and 0.5 mm. The optionally flexible properties of pressure measurement device **1000** renders pressure measurement device **1000** conformably adjustable on a surface of object **1050** which may attain or may have various shapes. For example, as is schematically demonstrated with FIG. **3**A, an object **1050** may have the shape of an airfoil having an upper and a lower surface **1051** and **1052**, respectively. By fittedly adjusting lower boundary **1102** of substrate **1100** on upper surface **1051** such that all or most of first apertures **1310** are located above upper surface **1051**, PSMs **1200** of respective first apertures **1310** are subjected to the pressure exerted by at least some of the fluid flowing over upper boundary **1051**. Thusly configured, the pressure exerted by fluid directly on upper surface **1051** at the corresponding planar locations of first apertures **1310** can be derived in accordance to the pressure being measured by PSMs **1200**. For example, if the pressure measured at a given first aperture **1310** by means of the respective PSM **1200** is about 20 millibars, it may for example be assumed that if substrate **1100** was not adjusted on object **1050**, approximately the same amount of pressure would be exerted by a fluid directly on upper surface's **1051** planar location that corresponds the location of the given first aperture **1310**. Thus, pressure measurement device **1000** enables obtaining an approximation of the pressure distribution on any objects' surface such as, for example, upper surface **1051** of object **1050**.

It should be noted that terms like "flowing over a boundary", "flowing over a surface" and grammatical variations thereof, include the meaning of "flowing on a boundary", "flowing at boundary", "flowing on a surface", "flowing at surface", and grammatical variations thereof.

For exemplary and simplification purposes only, the shape of object **1050** not having adjusted thereon pressure measurement device **1000** is hereinafter referred to as "original shape", whereas the shape of object **1050** having adjusted thereon pressure measurement device **1000** is hereinafter referred to as "new shape" of object **1050**, i.e., new shape of object **1050** takes into account the boundaries of pressure measurement device **1000**. Correspondingly, new upper surface **1051**, takes for example into account substrate **1100** adjusted thereon.

In some embodiments of the invention, pressure measuring device **1000** is conformably adjustable on object **1050** such that the new shape of object **1050**, which takes into account the boundaries of pressure, measurement device **1000**, deviates only minimally from object's **1050** original shape. Thusly configured, the measurements obtained by adjusting pressure measurement device **1000** on object **1050** provide a relatively accurate approximation of the pressure that would be exerted on object's **1050** surface by fluid, if pressure measurement device **1000** was not adjusted on object **1050**. Taking into consideration the above-mentioned requirements, substrate **1100** and/or PSMs **1200** may for example be as thin as possible and/or may have an aerodynamic shape to reduce drag and/or turbulence. For example, substrate **1100** and/or PSMs **1200** may be shaped such that the edges of either or both of them may be flush or substantially flush with the surfaces of object **1050**; that the thickness of substrate **1100** and/or PSMs **1200** is a small as possible; and/or that the protrusion of PSMs **1200** is as small as possible and/or that PSMs **1200** are for example aerodynamically (e.g. dome-) shaped. Correspondingly, in the event that one wants to measure the pressure distribution on upper boundary **1051** and PSMs **1200** protrude from substrate **1100**, it is advantageous to conformably adjust lower boundary **1102** of substrate **1100** on object **1050** such that PSMs **1200** are located below lower boundary **1052** as is schematically illustrated in FIG. **3**B. Thusly adjusted, flow of fluid over new upper boundary **1051** remains substantially unobstructed.

Substrate **1100** may be made of any suitable material such as, for example, a polymer material, which may be, e.g., polymide, polyester, polyethylene, polypropylene, Polyethylene terephthalate(PET), Polytetrafluoroethylene (PTFE), polyetheretherketone (PEEK) or as a sandwich structure of different polymers, metals, adhesives or any combination thereof.

According to some embodiments of the invention, a pressure measurement system **1001** may comprise pressure measurement device **1000** and a signal processing (SP) module **1400**. Further, at least one of PSMs **1200**, which is operatively connected to respective channels **1300**, may be adapted to transmit by wire (by means of, e.g., a flexible printed-circuit board (PCB) having integrated therein electron-conductive channels) or wirelessly data representing information about the relative or absolute pressure prevailing in channels **1300** to SP module **1400**, which may be adapted to analyze and display the information. SP module **1400** may for example, comprise a receiver (not shown), an analog-to-digital converter (not shown) and an amplifier (not shown) and a multiplexer (not shown), all of which are operatively connected to a power supply (not shown). Correspondingly, pressure measurement system **1001** may enable a user thereof to provide the user with an approximation of the pressure being present at locations on object's **1050** surface corresponding to the locations of first apertures **1310** on upper boundary **1101**. Hence, pressure measurement system **1001** enables to approximately map the pressure on upper surface **1051**.

Additional reference is now made to FIG. **3**B. Wired transmission of the information to SP module **1400** from PSMs **1200** that are arranged on object **1050** delineating a rotating movement around an axis **1600**, as is schematically indicated with arrow M, may not be suitable since the resulting rotating movement of PSMs **1200** may cause obstructive entanglement of communication wires operatively coupled to PSMs **1200**, and PSMs **1200** may thus be decoupled from the SP module handling and transmitting the pressure data. In distinct contrast, PSMs **1200** that are adapted to transmit data wirelessly are employable on rotating objects (e.g., propellers, turbine blades) for the transmission of the pressure information to SP module **1400**, since the omission of communication wires eliminates the problem of obstructive entanglement. It should further be noted that employing PSMs **1200** adapted to transmit data wirelessly, may substantially reduce the set-up time of pressure measurement system **1001**, since no communication wires have to be guided from and/or along object **1050** to SP module **1400**. Accordingly, pressure measurement device **1000** may include at least one wireless transmission module (not shown) that is operatively coupled to or integrated in PSMs **1200**. To enable such wireless transmission, the wireless transmission module may comprise, inter alia, of an amplifier and a control module all or some of which may be integrated, for example, in substrate **1100**.

Referring now to FIG. **4**A a PSM **1200** may optionally be embodied by an absolute PSM **4201**. Absolute PSM **4201** may include a membrane **4210**, which may be concavely shaped. Membrane **4210** is responsively positioned in absolute PSM **4201** with regard to the pressure that may prevail in channel **1300**. Correspondingly, as is schematically illustrated in FIG. **4**A, membrane **4210** may be fixedly adjusted by suitable absorption means **4220** within membrane **4210** such that at least some of lower boundary **4212** thereof faces second aperture **1320** of channel **1300**. Such absorption means **4220** may be embodied or may also have properties of, for example, adhesives which are sandwiched between membrane **4210** and upper boundary **1101** of substrate **1100**. The adhesives may be flexible and/or pliable to minimize and/or cancel out and/or compensate in membrane **4210** for a possible deflection or movement of substrate **1100**. Membrane **4210** and substrate **1100** may each have different temperature-based coefficient of expansions. Therefore, membrane **4210** and substrate **1100** may be coupled to each other and/or configured in a manner to be unaffected by such different temperature-based difference in expansion. For example, absorption means such as, for example, absorption means **4220** may therefore be made of a material having a relative low modulus of elasticity of, e.g., less than 2 GPa, to avoid generating stress in membrane **4210** that may be generated due a difference in temperature-based expansion between membrane **4210** and substrate **1100**. Examples for suitable materials of which absorption means may be made of are silicon; and epoxy or even solder material with underfill if concave portion of membrane **4210** faces upwardly (i.e., away from) second opening **1320**. Membrane **4210** may be made, for example, of a monocrystalline silicon. To enable the conductance of a signal that corresponds to the deflection of membrane **4210** outside substrate **1100**, at least some portions of absorption means **4220** may be conductive (e.g. at least at the contact area between membrane **4210** and absorption means **4210**).

It should be noted that in order to enable vertical displacement of upper boundary **4211**, as is schematically indicated with arrow D_{up}, at least some part of upper and lower boundary **4211** and **4212**, respectively, ought to be positioned in front of respective cavities **4213** and **4214**. Such cavities may be established, for example, by employing a sensor membrane of which at least one side thereof, which is positioned opposite to second aperture **1320**, is concavely formed, whereas only the edges of the other side of the same sensor membrane are being supported by absorption means **4220**. For example, as is schematically illustrated, inter alia, in FIG. **4**A, upper boundary **4211** is concavely formed, whereas lower boundary **4212** is only supported on the edges by absorption means **4220**. Thusly configured, membrane **4210** may move in accordance to the pressure exerted thereon. For example, if the pressure established in channel **1300** is higher than the pressure prevailing in upper cavity **421**, then membrane **4210** may deflect upwardly as is schematically indicated with arrow D_{up}.

It should be noted that when referring to absolute PSMs such as, for example, absolute PSM **4201**, then the pressure in cavity **4213** is hereinafter referred to as "$P_{reference\_abs}$", which may be close to a pressure corresponding to vacuum, or which may be significantly smaller than the pressure prevailing in channel **1305** by, e.g., at least 10 factors when under normal conditions (e.g. when pressure in channel **1305** is about equal to atmospheric pressure. The pressure prevailing in channel **1305** is hereinafter referred to as $P_{channel}$. Consequently, $P_{channel}$ may correspond to an absolute pressure value prevailing at first opening **1310** and membrane **4210** may only deflect upwardly (D_{up})

It should further be noted that for exemplary purposes only and to simplify the discussion herein, the pressure against which $P_{channel}$ is measured may also include or take into account the pressure exerted by membrane **4210** itself due to the mechanical properties thereof. Therefore, making reference to a term like "pressure prevailing in upper cavity, may also include the pressure that is exerted against $P_{channel}$ due to the mechanical properties of membrane **4210**.

Moreover, it should be noted that other configurations enabling the deflection of membrane **4210** in response to pressure may be possible, as outlined hereinafter.

Absolute PSM **4201** may further include an interface unit **4230** that may be responsively connected to membrane **4210**, which may be embodied, for example, by means of a piezo-responsive (e.g. piezo resistive or -electric) material that is operatively coupled to interface unit **4230**. Such a piezo-responsive material is responsive to the material's deflection and/or bending, and/or movement. Such deflection, bending, and/or movement may be caused by mechanical stress applied on the piezo-responsive material. Accordingly, interface unit **4230** may be embodied by an electronic circuit that is responsive to the changes of the electrical resistance. For example, interface unit **4230** may be adapted to convert these changes of electrical resistance into current changes. Additionally or alternatively, interface unit **4230** may be adapted to convert these changes of electrical resistance into corresponding voltage changes. Non-limiting examples of materials of which interface unit **4230** may be made of include glass (e.g. Pyrex, Borofloat) and silicon. Other suitable materials may be used.

It should be noted PSM **1200** may be embodied by alternative types of sensors, e.g., as known in the art such as, for example, capacitive sensors or acoustic sensors, wherein in case of acoustic sensors, channels **1300** may act as acoustic waveguides.

To maximize the accuracy of the absolute pressure measure exerted on membrane **4210**, upper cavity **4213** as well as lower cavity **4214** are sealed. In addition, the pressure $P_{reference\_abs}$ prevailing in upper cavity **4213** may be equal or close to vacuum. It should be noted that the meaning of the term "sealed" also encompassed the meaning of the term "substantially sealed" and the like. It should also be noted that the meaning of the term "vacuum" as used herein encompasses the meaning of the terms "substantial vacuum", "approximate vacuum" and the like.

Optionally, PSM **1200** may be equipped with a protective coating which may have various shapes. For example, as is schematically indicate in FIG. **4**A, a protective coating may be implemented by a dome-shaped coating **4241** and may be useful to protect conductive contacts (like, e.g. contacts **4215**) from corrosion. Parylene or any other suitable material may be employed as a protective coating.

Pressure measurement device **1000** may be used to measure hydrodynamic pressure. For example, flow of liquid **1500** against second aperture **1320** of channel **1300** may result in the generation of an airpocket **1305** trapped between liquid **1500** and lower side of membrane **4210**. The pressure $P_{channel}$ exerted on membrane **4210** corresponds to the pressure exerted by liquid **1500** on the airpocket **1305**. Therefore, hydrodynamic pressure may be measured by means of pressure measurement device **1000**. It should be noted that measuring hydrodynamic pressure is for exemplary purposes only outlined in association with absolute PSM **4201**, though other PSMs may be used for the measurement of hydrodynamic pressure as well

It should further be noted that all absolute PSMs outlined hereinafter are similarly configured as absolute PSM **4201**, except for the differences indicated.

Turning now to FIG. **4**B, an absolute PSM **4202** is schematically illustrated, which may be equipped with a protective cover that may be embodied, for example, by a rectangularly shaped housing **4242** made of, e.g., any suitable material such as, e.g., flame resistant-(FR) 4 used for printed circuit boards. It should be noted that meaning of the term "rectangular" and grammatical variations thereof also encompasses the meaning of the term "substantially rectangular" and "approximately rectangular". To enable the conductance of a signal that corresponds to the deflection of membrane **4210** outside substrate **1100**, at least some suitable portions of absorption means **4220** may be conductive (e.g. at least at the contact area between membrane **4210** and absorption means **4210**).

Turning now to FIG. **5**A and FIG. **5**B, PSMs **1200** may be embodied, for example, by an absolute PSM **5201** and **5202**, respectively. PSMs **5201** may include, for example, absorption means **5220** that are sandwiched between membrane **4210** and substrate **1100**. As outlined hereinabove, membrane **4210** and substrate **1100** may each have different temperature-based coefficient of expansions. Thus, absorption means such as, for example, absorption means **5220** may be positioned between membrane **4210** and substrate **110**, made of a material having a relative low modulus of elasticity of, e.g., less than 2 GPa, to avoid generating stress in membrane **4210** due a difference in temperature-induced expansion between membrane **4210** and substrate **1100**. Such absorption means **5220** may comprise of a support **5226** that may include conducting-through-holes **5227** to enable sending to SP module **1400** signals generated due to pressure-induced deflection of membrane **4210**. Support **4226** may be made of any suitable material such as, for example, pyrex or silicon based material. Optionally, as is schematically illustrated in FIG. **5**A, absolute PSMs **5201** may comprise a protective cover such as, for example, dome-shaped coating **4241**. Additionally or alternatively, as is schematically illustrated in FIG. **5**B, an absolute PSM **5202** may be equipped with a protective cover embodied by housing **4242**, which may be made of a substrate.

Further referring now to FIG. **6**, PSM **1200** may optionally be embodied by absolute PSM **6200** comprising absorption means **4220** and **5220**, respectively. Interface unit **5230**, which comprises an opening **5231**, is sandwiched between membrane **4210** and either to respective absorption means **4220** or **5220**. As is schematically illustrated in FIG. **6**, concave portion of membrane **4210** faces opening **5231**. Absolute PSM **6200** may include a protective cover, which may be implemented by housing **4242**, sealing membrane **4210**, interface unit **5230** and absorption means **4220** from the ambient pressure, such that a vacuum may prevail in a cavity **6213** encompassed by said cover. Thusly configured, pressure $P_{channel}$ may work by means of membrane **4210** against a relatively very low reference pressure $P_{reference\_abs}$ of, e.g., 100 Pascal.

Generally speaking, differential pressure devices may be employed for the measurement of both small and large pressure variations and/or ranges, whereas absolute pressure sensor devices may only employable for the measurement of relatively large pressure variations. However, absolute pressure sensing device may in general be more simple devices as they may employ fewer elements than differential pressure devices.

Wire-bond **4221** may be made, for example, of gold or aluminum. Thusly, wire-bond **4221** may conduct signals that correspond to the deflection of membrane **4210**, and both absorption means **4220** and interface unit **5230** can be made of insulating materials.

Reference is now made to FIGS. **7**A, **7**B, **8**A, **8**B and **9**A, all of which schematically illustrate PSMs **1200** that are embodied by differential PSMs (The current PSM has N−1 differential pressure sensors, to measure the differential pressure to the reference pressure on the strip and 1 absolute pressure sensor to measure the reference pressure). It should be noted that the differential PSMs are all similarly configured, except for the differences indicated.

As is schematically illustrated in FIG. **7**A and FIG. **7**B, differential PSMs **7201** and **7202** may each comprise absorption means **4220** that are sandwiched between substrate **1100** and membrane **4210**. In addition, membrane **4210** is sandwiched between interface unit **5230** and absorption means **4220**, whereby the concave part of membrane **4210** faces interface unit **5230**. As already indicated herein, interface unit **5230** comprises an opening **5231**, which may be open to pressure $P_{reference\_diff}$, which may be significantly higher than pressure $P_{reference\_abs}$ of a cavity such as, for example, cavity **4213**, prevailing in upper cavity **4213** of absolute PSM **4201**. Accordingly, upper cavity **7213** of differential PMS **7201** and **7202** may not have to be sealed and may thus, for example, be open to the atmosphere and accordingly be equal or close to atmospheric pressure. Fittedly adjusting on object **1050** a differential PSM pressure such as, for example differential PSM **7201** or **7202**, may facilitate that membrane **4210** might not only deflect upwardly, as is schematically indicated with arrow D_{up} but also downwardly, as is schematically indicated with arrow D_{down}. If for example, $P_{reference\_diff}$ equals to about, e.g., 100,000 Pascal (which may be considered as atmospheric pressure) and if pressure $P_{channel}$ is lower than 100,000 Pascal (e.g. 98,000 Pascal), then membrane **4210** may deflect downwardly (D_{down}). Conversely, if pressure P-channel established in channel **1300** is higher than the pressure $P_{reference\_diff}$, then membrane **4210** may deflect upwardly, as is schematically indicated with arrow D_{up}.

Differential PSM **7201** may optionally be equipped with a protective cover **7241** (FIG. **7**A), which may have a dome-like shape and manufactured, e.g., as known in the art, from a glob top. Cover **7241** may have an opening **7242** that may be open to pressure $P_{reference\_diff}$ and operatively connected opening **5231** such that the upper side of membrane **4210** subjected to the pressure $P_{reference\_diff}$. Additionally or alternatively, as is schematically indicated in FIG. **7**B, a protective cover may be implemented by a rectangularly shaped housing **7242**, which may have an opening **7243** that is subjected to reference pressure $P_{reference\_diff}$. Alternatively, instead of substrate **1100**, a substrate **7100** may be employed having an opening **7115** which is open to reference pressure $P_{reference\_diff}$. However, in either embodiment, pressure $P_{channel}$ prevailing in channel **1300** may work against the pressure $P_{reference\_diff}$. Accordingly, both differential PMS **7201** and **7202** may enable differential pressure measurements.

Referring to both FIG. **7**A and FIG. **7**B, at least some portion of absorption means **4220** may be conductive (e.g. by employing a conductive adhesive or solder) to enable the conductance of a signal generated due to a deflection of membrane **4210**.

Further reference is now made to FIG. **8**. According to some embodiments of the invention, a differential PSM **8201** may include absorption means **5220** beneath membrane **4210**, instead of absorption means **4220**.

It should be noted that configuring a PSM wherein concave side of membrane **4210** faces upwardly (i.e., away) from second opening **1320**, may be useful in absolute PSMs (e.g. absolute PSM **5201**), since such a configuration facilitates the guiding of pressure-induced signals out of the same absolute PSM.

Additional reference is now made to FIGS. **9**A and **9**B. According to some embodiments of the invention, a differential PSM **9201** and **9202** may be configured such that interface unit **5230** is sandwiched between membrane **4210** and either absorption means **4220** or **5220**, respectively. Membrane **4210** may be provided onto interface unit **5230** such that the concave part of membrane **4210** faces opening **5231** of interface unit **5230** (and is thus subjected to $P_{channel}$), whereas the other side of membrane **4210** is subjected to reference pressure $P_{reference\_diff}$. Optionally, both differential PSM **9201** and **9202** may comprise protective coating **6240**, which may have an opening **6241** open to pressure $P_{reference\_diff}$. In some embodiments of the invention, substrate **7100** having an opening **7115** open to reference pressure $P_{reference\_diff}$ may be used instead of substrate **1100**.

As an alternative to wire-bond **4221** (FIG. **9**A), differential PSM **9201** may employ for example, electrically conducting "Vias" such to conductively connect membrane **4210** with absorption means **4227** to an electric circuit (not shown) of a substrate such as substrate **7100**. Similarly, differential PSM **9202** (FIG. **9**B) may be configured such to conductively connect membrane **4210** with absorption means **5227** to the electric circuit (not shown) of substrate **7100**. It should be noted alternative configurations may be employed for the conductive coupling of membrane **4210** with a substrate.

It should be noted that in some embodiments of the invention, pressure measurement device **1000** may comprise at least one absolute PSM as well as at least one differential PSM. Pressure measurement device **1000** may for example include N−1 differential PSM and 1 absolute PSM, wherein "N" represents the total number of PSMs in pressure measurement device **1000**. Employing an absolute PSM is necessary to obtain $P_{reference\_abs}$ to able determining $P_{channel}$. Moreover, in some embodiments of the invention, pressure measurement device **1000** may be configured to measure $P_{reference\_diff}$ by employing, e.g., one or more suitable PSMs.

Reference is now made to FIG. **10**A and to FIG. **10**B. In some embodiments of the invention, pressure measurement device **1000** may employ one absolute PSM **10201**A and a plurality of differential PSMs such as, for example, differential PSMs **10201**B, **10201**C, **10201**D, which are hereinafter referred to for exemplary purposes only. As is schematically illustrated, the upper part of all membranes **4210** is subjected to a single or substantially single reference pressure $P_{reference}$ prevailing at an inlet of substrate **1100**, or which prevails at numerous inlets **1310** that are crowded closely together (i.e., the planar center-points of the numerous inlets **1310** are not more than 1 mm distant from each other. Further, the lower parts of membranes **4210** of the plurality of differential PSMs **10201**B, **10201**C and **10201**D only are individually subjected to a respective pressure $P_{Pressure}$ prevailing in each channel **1310**. Thusly configured, the value of the $P_{reference\_diff}$ can be determined by means of absolute PSM **10201**A, consequently enabling determining the pressure $P_{channel}$ relative to $P_{reference\_diff}$.

An absolute PSM and/or a differential PSM such as, for example, absolute PSM **10201**A and/or differential PSM **10201**B may be covered by means of a detachable cover **1106** (made of, e.g., plastic) coupled to a PCB **1105**, which may be made of a substantially rigid material. Accordingly, PCB **1105** and cover **1106** may thus constitute a protective housing such as, for example, housing **4242**.

Further, one or more PSMs, such as PSMs **10201**A and **10201**B may be coupled onto substrate **1100** by means of a double-sided adhesive tape **1107**.

Reference is now made to FIG. **11**A. As indicated by box **11100**, a method for manufacturing a pressure measurement device **1000** according to an embodiment of the invention, may include, for example, providing a substrate such as substrate **1100** or substrate **7100**. Such a substrate has planar-like dimensions enabling large-area covering of at least some part of the surface of object **1050**.

Further, as indicated by box **11200**, the method may include according to some embodiments of the invention, manufacturing at least one channel **1300** into the substrate, which may be embodied by substrate **1100** and/or substrate **7100**. Such a channel **1300** may have a diameter that may range, for example, from 0.05 mm to 0.5 mm. Manufacturing of channels **1300** may be performed by employing a micro-milling machine.

As indicated by box **11300**, the method may for example include providing absorption means around second aperture **1320** of channel **1300**. Such absorption means may be embodied, for example, by absorption means **4220** or **5220**. Absorption means **4220** and/or **5220** may be configured to compensate for movement of the substrate and may therefore be soft/pliable.

As indicated by box **11600**, the method may include, for example, providing a protective coating over coupling means (e.g. absorption means **4220**), membrane **4210** and an interface unit (e.g. interface unit **5230**). The protective coating may be embodied, for example, by a dome-shaped coating **4241**, which may be provided, for example, in the form of a glob top silicone substrate.

It should be noted that at least some of the elements of pressure measurement device **1000** may be manufactured, e.g., as known in the art. For example pyrex backing may be employed for manufacturing at least some of the device's elements.

In some embodiments of the invention, pressure measurement device **1000** is adapted to conformably adjust itself to contour changes of object **1050**, even if pressure measurement device **1000** is already operatively adjusted on, e.g., upper surface **1051**.

It should be noted that pressure measurement device **1000** may have alternative configuration to what has been described thus far. For example, channels **1300** may be configured such that some or all of PSMs **1200** are located on front surface **1103** of substrate **1100**.

According to some embodiments of the invention, as indicated by box **11700**, a method for using pressure measurement device **1000** and/or system **1001** may inter alia comprise the step of mechanically coupling measurement device **1000** by, e.g., low-force adhesives. Such adhesives establish a force of about less than 50 Newton (/cm^2) and preferably of less than 10 Newton/(cm^2).

Embodiments of the present invention may have advantages over U.S. Pat. No. 5,359,887 (hereinafter referred to as "patent '887"). As outlined herein, embodiments of the present invention enables direct measurement of the pressure distribution on at least some parts of the surface of object **1050**. In distinct contrast, patent '887 only enables indirectly deriving a pressure by means of a pressure sensitive paint. Such a pressure sensitive paint may not be adjustable or easily adjustable to compensate for temperature-fluctuation induced measurement changes. Also, accuracy of pressure sensitive paint is limited to a maximum of about 0.5 bars, whereas embodiments of pressure measurement device **1000** enable measuring pressure at an accuracy of a few tenth of millibars. In contrast, embodiments of the present invention may be easily adjusted to compensate for measurement changes caused by temperature fluctuations. In addition, pressure sensitive paints may not be employed when being exposed to light (e.g., sunlight). In contrast, embodiments of the invention may be employed on objects exposed to light. As opposed to pressure sensitive paints, embodiments of the invention may not contaminate object **1050** and/or surrounding ambient, may be used for the pressure measurement exerted by other fluids than air.

The present invention may also have advantages over U.S. Pat. No. 5,983,727, which discloses a sensor that is based on change of capacitance. This measuring method indirectly measures the distance between the two insulating plates instead of measuring the pressure/force on the membrane directly. This type of sensor is susceptible to temperature and/or mechanical stress. Moreover, polymer membranes as opposed to monocrystalline silicon membranes do have a hysteresis. Capacitance is more susceptible to electromagnetic fields than sensors based on piezo-responsive materials.)

The present invention may further have advantages over U.S. Pat. No. 6,662,647. Packaging of the present invention is far less complex and PSMs of the present invention may be located away from the locations of an object's boundary for which pressure is to be measured. Moreover, the invention disclosed in disclosed in U.S. Pat. No. 6,662,647 does not enable measuring the pressure distribution for a large area. Further in contrast to U.S. Pat. No. 6,662,647, the present invention is less susceptible to hysteresis.

Embodiments of the present invention may also have advantages over U.S. Pat. No. 6,826,968 such as, for example, in that embodiments of the present invention are far less sensitive to electrical noise than capacitive sensors (implemented as e.g. compressible dielectrics). Piezo-resistive pressure sensors have a silicon membrane which is monocrystalline and may therefore have a much smaller hysteresis than polymer membranes. As already indicated herein, capacitive based sensors are based on the on differences in distance whereas sensors employing piezo-responsive material measure the stress exposed on the membrane due to pressure directly.

Embodiments of the present invention may also have advantages over U.S. Pat. No. 7,127,948 such as, for example, in that PSMs may be distantly located from the area for which pressure ought to be measured.

Pressure measurement device **1000** and system **1001** may have additional advantages over the devices and systems used in the art. Pressure measurement device **1000** does not have hysteresis, as it is implemented by means of piezo-responsive materials, has high pressure sensitivities of, e.g., 20 mV/kPa or 2 mV/mbar (without amplification), and enable therefore measuring a pressure at a relatively high resolution compared to, for example, capacitively based pressure sensors. Membrane **4210** may be made of a monocrystalline material and may thus not be subjected to any mechanical wear compared to other material such as polymer based sensors, which may be employed, for example, in piezoelectric and compressible dielectric based PSM. In some embodiments of the invention, pressure measurement device **1000** and optionally pressure measurement system **1001** may be employed under harsh environmental conditions (e.g. temperature, dust, dirt and the like) and may be waterproof. Pressure measurement device **1000** may be easily repositionable by using, for example, low-force coupling means (e.g. low-force adhesives) to conformably couple device **1000** onto object **1050**.

While the invention has been described with respect to a limited number of embodiments, these should not be construed as limitations on the scope of the invention, but rather as exemplifications of some of the embodiments. Those skilled in the art will envision other possible variations, modifications, and programs that are also within the scope of the invention. Accordingly, the scope of the invention should not be limited by what has thus far been described. Therefore, it should be understood that alternatives, modifications, and variations of the present invention are to be construed as being within the scope of the appended claims.

What is claimed is:

1. A pressure measurement device, said pressure measurement device comprising:

a substrate having at least one fluid-conductive channel therein, each channel of the at least one channel having a first aperture at a first end thereof and a second aperture at a second end thereof; and

at least one pressure sensing module, each of the at least one pressure sensing module being

operatively connected to a corresponding second aperture;

wherein said substrate is flexible such that said pressure measurement device is conformably adjustable onto an object's surface; and

wherein each first aperture and each second aperture of each channel of said at least one channel are located on a surface of said substrate such that when said substrate is suitably adjusted onto the object's surface, each aperture of said at least one first aperture is open to the exterior of said object's surface, and

each channel corresponding to each open first aperture is structured and arranged so that a pressure sensing module disposed at the second end thereof is substantially subjected to pressure at said open first aperture.

2. The pressure measurement device according to claim **1**, wherein said at least one first aperture is remotely located from the pressure sensing module.

3. The pressure measurement device according to claim **1**, wherein said pressure sensing module comprises a membrane made of a piezo-responsive material.

4. The pressure measurement device according to claim **3**, wherein said piezo-responsive material is one of a piezoresistive and piezo-electric material.

5. The pressure measurement device according to claim **3**, further comprising an interface unit responsive to changes in the piezo-responsive material membrane and absorption means sandwiched between said substrate and one of said membrane and said interface unit to avoid generating stress in said membrane generated due a difference in temperature-based expansion between said membrane and said substrate.

6. The pressure measurement device according to claim **1**, wherein said pressure sensing module is one of an absolute pressure sensing module and a differential pressure sensing module.

7. The pressure measurement device according to claim **1**, said at least one channel having a diameter ranging between 0.05 and 0.5 mm.

8. The pressure measurement device according to claim **1**, wherein said substrate has a thickness of less than 1 mm.

9. A pressure measurement system, said system comprising:

a signal processing (SP) module; and

a pressure measurement device that includes:

a substrate having at least one fluid-conductive channel therein, each channel of the at least one channel having a first aperture at a first end thereof and a second aperture at a second end thereof, wherein said substrate is flexible such that said pressure measurement device is conformably adjustable onto an object's surface, and

at least one pressure sensing module (PSM), each of said at least one PSM being operatively connected to said SP module,

wherein each of said at least one pressure sensing module is operatively connected to a corresponding second aperture;

wherein each first aperture and each second aperture of each channel of said at least one channel are located on a surface of said substrate such that when said substrate is suitably adjusted onto the object's surface, each aperture of said at least one first aperture is open to the exterior of said object's surface, each of said at least one PSM therefore generally being substantially subjected to a pressure present at a corresponding first aperture of said at least one first aperture.

10. The pressure measurement system according to claim **9**, wherein said PSM is adapted to transmit wirelessly to said SP module data representing information about the pressure prevailing in said channels.

11. The pressure measurement system according to claim **9**, wherein said first at least one aperture is located remotely from said PSM.

12. The pressure measurement system according to claim **11**, wherein said first at least one aperture is located remotely from said PSM by at least 10 cm.

13. The pressure measurement system according to claim **9**, wherein said at least one PSM is one of an absolute PSM and a differential PSM.

14. A pressure measurement device, said pressure measurement device comprising:

a substrate having at least one fluid-conductive channel therein, each channel of the at least one channel having a first aperture and a second aperture;

at least one pressure sensing module having a membrane made of a piezo-responsive material,

wherein said pressure sensing module is operatively connected to a corresponding second aperture;

an interface unit responsive to changes in the piezo-responsive material membrane; and

absorption means sandwiched between said substrate and one of said membrane and said interface unit, to avoid generating stress in said membrane generated due to a difference in temperature-based expansion between said membrane and said substrate;

wherein said substrate is flexible such that said pressure measurement device is conformably adjustable onto an object's surface, and wherein said at least one first aperture is located on said substrate such that when said substrate is suitably adjusted onto the object's surface, said at least one first aperture is open to the exterior of said object's surface, said at least one pressure sensing module is substantially subjected to a pressure at said at least one first aperture.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 7,788,981 B2
APPLICATION NO. : 12/075864
DATED : September 7, 2010
INVENTOR(S) : Noa Schmid et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 9, line 7, “pressure, measurement” should read -- pressure measurement --; and

Column 13, line 53, “P-channel” should read -- $P_{channel}$ --.

Signed and Sealed this
Second Day of October, 2012

David J. Kappos
Director of the United States Patent and Trademark Office